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VOLUME LIII NUMBER 1

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OUTLINE OF THE GEOLOGY OF CUBA

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ABSTRACT

Cuba is approximately 700 miles long and 50 miles wide. It is divided into eight physiographic provinces which roughly correspond to geological features. The geological column ranges from Middle Jurassic to Pleistocene. Much of the Middle and Lower Cretaceous is missing or has not been identified. There was extensive Cretaceous volcanism. The Upper Cretaceous and Tertiary have an abundant, well-preserved fauna. The Eocene and Oligocene faunas are Old World in contrast to the Miocene fauna, which is New World in relationships. The Tertiary is well represented from the Paleocene through the Miocene. The Upper Cretaceous and the Paleocene are land-derived sediments of unknown geographical origin. The remaining are largely marls and limestones.

There are both extrusive and intrusive rocks. Basic and acid rocks occur in both types.

There are various structures of diverse ages. In the west is a large overthrust followed by two large anticlines to the east. A large overthrust area including the Trinidad Mountains and intrusions occupy the central part of the island. A broad syncline with extensive intrusions forms the eastern end, with a mass of metamorphics lying at the extreme east.

Cuba in its present form dates from late Miocene. Previously the area was occupied by scattered islands or was completely submerged. During late Cretaceous and the Paleocene, portions of what is now Cuba were part of a large land mass that extended as far south as Jamaica.

Since assuming its present form, Cuba was submerged in the Pleistocene or Recent. This accounts for the paucity of land fauna on the island.

INTRODUCTION

The island of Cuba is 1,200 kilometers (720 miles) long with an average width of about 85 kilometers (50 miles). The eastern two-thirds (750 kilometers) lies in a straight line with a bearing of N. 70° W.; the following 200 kilometers lies in an east-west line, and the western 200 kilometers has a bearing of S. 65° W. The 80° meridian and the 22° parallel intersect near the center of the island. Cuba is bounded on the north by the Bahama Channel and the Gulf of Mexico and on the south by the Yucatán Basin and by the east end of the Bartlett Deep.

Recent submergence has left much of Cuba bordered by shallow water and numerous cays. Reference to the map (Fig. 1) shows that with an emergence of 8 fathoms these shoals and cays would become part of the mainland. The resulting outline would give a true picture of Cuba as an island mass surrounded by deep water.

TOPOGRAPHY AND PHYSIOGRAPHY

Cuba may be divided into eight physiographic provinces as follows:

1. The Organos Mountains that lie in the northern half of Pinar del Río Province. This range is 140 kilometers (85 miles) long and from 6 to 14 kilometers (3.5 to 8.5 miles) wide, with elevations to 1,500 feet. It consists essentially of a

FIG. 1.—Map showing principal geological features and general distribution of Cretaceous, Tertiary, and igneous rocks in Cuba. Note re-entrant of 1,000-fathom line between Gulf of Mexico and the Pinar overthrust and a second between the Antillean Sea (Yucatán basin) and the Trinidad overthrust. The arrows indicate the direction of thrust (*Vergens* as used by Stille).

sheet of hard Cretaceous limestone overlying younger Cretaceous shales and sandstones of the Cayetano formation in an overthrust position. On the south side of the western end the range is broken up into large isolated blocks known as "mogotes." These mogotes are the most striking feature of the landscape of Viñales Valley (Fig. 2). Elsewhere, particularly in the eastern end of the range, erosion has left much larger masses of the overthrust sheet that completely cover the Cayetano except where the latter is exposed in the deeper stream beds.

The limestone mogotes support an abundant flora in spite of the scarcity of soil. The shales, on the contrary, have scant vegetation, but this is notable for pines and oaks which are rare elsewhere in Cuba and in striking contrast to the palms which elsewhere characterize Cuban scenery.

This province also includes the relatively high and deeply incised Cayetano shales area bordering the Organos Mountains on the south in a belt 8–12 kilometers wide.

2. The Cayetano Plain lies between the Organos Mountains and the north coast, west of the meridian passing through Pinar del Río City. It is a relatively small area 60 kilometers long by 10 kilometers wide and lies on the Cayetano formation. It is characterized by steep drainage courses near the mountains and by low, flat land nearer the coast. As on the outcrops of the same formation within the mountains, the vegetation is scanty.

3. This is the folded zone occupying the northern half of Habana Province and extending eastward to about the middle of Matanzas Province. It includes the Habana-Matanzas and Madruga anticlines and the Almendares–San Juan syncline between them. Along both anticlines erosion has removed the Tertiary limestone and exposed the softer Cretaceous shales, producing a topography of low, rolling hills flanked on either side by Tertiary limestone cliffs. The soil derived from the Cretaceous is considered mediocre in Cuba. Cane is its principal crop.

4. South of the Organos Mountains and the folded zone in Habana and Matanzas provinces and extending eastward to about the Cienfuegos meridian in Santa Clara Province is the flat Coastal Plain. In western Matanzas Province an arm of this plain crosses the island to the north coast. This physiographic province is a monotonous plain characterized by red soil, many sinkholes, and underground drainage. A belt of sand and terrestrial debris borders the south coast. The red soil is derived from the underlying Güines limestone and, even where there is only a shallow accumulation, produces the finest cane land in Cuba. Where the rock is at or near the surface, precipitation quickly enters the porous limestone resulting in desert conditions and a xerophytic flora.

5. Santa Clara (or Las Villas) Province[1] forms a single, complicated physiographic province. A zone of overturned folds and overthrusts, called the "Cordillera," lies along the north coast. This has been reduced to low ridges by erosion. South of the Cordillera is a large area characterized by several types of intruded rocks that stand out as hills up to 600 feet in height. In the southern part of the province are the Trinidad Mountains, with peaks nearly 3,000 feet high.

6. A second coastal plain occupies the

[1] The official name of Santa Clara Province has been recently changed to Las Villas. Since the current maps all bear "Santa Clara," that name has been used here.

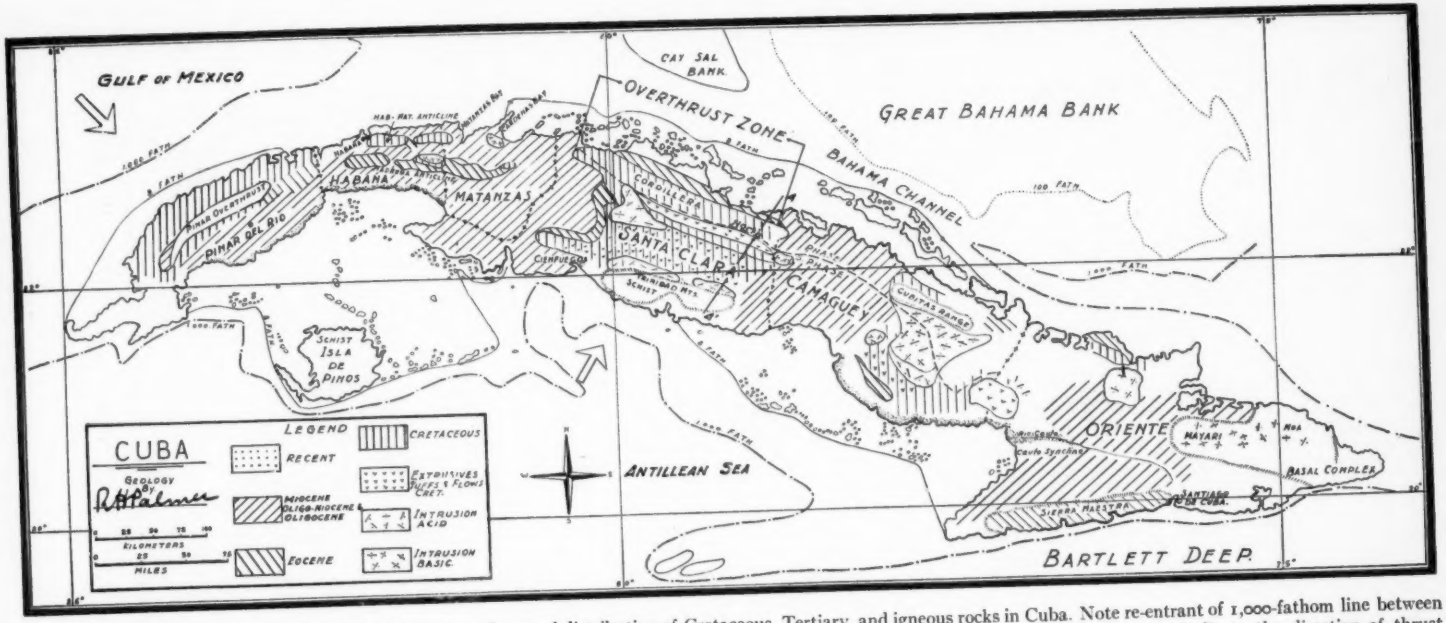

FIG. 1.—Map showing principal geological features and general distribution of Cretaceous, Tertiary, and igneous rocks in Cuba. Note re-entrant of 1,000-fathom line between Gulf of Mexico and the Pinar overthrust and a second between the Antillean Sea (Yucatán basin) and the Trinidad overthrust. The arrows indicate the direction of thrust (*Vergenz* as used by Stille).

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FIG. 2.—Looking north across Viñales Valley. The "mogotes" (isolated hills) are remnants of the dissected Viñales limestone sheet thrust from the northwest over the Cayetano shales that form the valley floor. (Photograph by Dr. Roberto Machado.)

southern half of Camagüey Province and extends eastward across the Cauto Valley to the Sierra Maestra in Oriente Province. As in the western Coastal Plain, a broad arm crosses the island to the north

7. The folded and intruded area in northeastern Camagüey and Oriente provinces.

8. The Sierra Maestra in the southern part of Oriente Province and the mountainous zone in the eastern portion of the same province.

TABLE 1

COLUMN*

	Series	Formation	Description
Tertiary	Miocene	Matanzas	marl
			unconformity
		La Cruz	marl
	Oligo-Mio.	Güines	limestone
	Oligocene	Cojimar	chalk
			unconformity
		Tinguaro	marl
	Eocene	Príncipe	chalk
		Universidad	chalk
			unconformity
	Paleocene	Capdevila	sh, ss, cgl
Mesozoic	Cretaceous	Habana	ss, sh, ls, cgl, tuff (Land derived)
		Cayetano	sh, ss (Land derived)
		Provincial	ls with sh beds
			unconformity
		Aptychus Beds (Viñales)	ls, few shales
			(Tuff Series)
	Jurassic	Quemado	ls
		Jagua	schistose ls
	?	Santa Fé Schists, Gerona Marble, Trinidad Schists	
	?	Basal Complex in Oriente (Taber)	

*The principal formations only are given in the column. Unimportant formations, faunal zones, and other small subdivisions are omitted.

coast. This lies between the Cordillera and the meridian passing through Camagüey City. It also resembles the western Coastal Plain in being underlain for the most part by the same Güines limestone capped by the same rich soil. So similar are the two coastal plains that they may be considered a single unit interrupted by the Trinidad Mountains.

These eight physiographic provinces correspond for the most part to geological features that will be described later.

PALEOZOIC?

In the eastern end of Cuba there is an area of badly sheared and contorted

schists which S. Taber[2] calls the "Basal Complex" and believes to be Paleozoic. The age determination is based entirely on lithology, as no fossils have been found in the series.

SANTA FÉ SCHISTS, GERONA MARBLE, AND TRINIDAD SCHISTS

In the Trinidad Mountains of southern Santa Clara Province there is a thick series of hornblende, micaceous, and calcareous schists. On the Isle of Pines there is a similar series of hornblende, micaceous, and quartz schists and phyllites with a thick limestone member that is altered to marble. The schist series on the Isle of Pines, C. W. Hayes, T. W. Vaughan, and A. C. Spencer[3] named the "Santa Fé schists" and the limestone the "Gerona marble." Many lithologic similarities have suggested tentative correlation of the two metamorphic areas.[4] Neither series is fossiliferous, hence their age is not known. The opinion has also been expressed that the marbles and schists of the Isle of Pines are the metamorphic equivalents of the Viñales limestone and the Cayetano shales in the Organos Mountains of Pinar del Río Province,[5] but no supporting evidence has been offered. Rutten[6] bases the correlation on lithologic grounds. The Pinar del Río series has not been metamorphosed except locally where shearing has been intense or near intrusions, while on the Isle of Pines the entire mass has been altered to marbles and schists. However, the thinly bedded, 34,500 feet of Cayetano shales with thick lenses of sandstone are suggestive of the thinly bedded micaceous and quartz schists of comparable thickness[7] of the Isle of Pines. This is particularly true of the siliceous phase of the Cayetano nearest the Isle of Pines toward the southwest end of the Organos Mountains.

JURASSIC

JAGUA FORMATION

The oldest formation in Cuba whose age determination is based on fossil evidence belongs to the Jurassic. This is a very thinly bedded, shaly limestone of nearly schistose structure that outcrops at the base of some of the northern mogotes in Pinar del Río Province. It has a thickness of about 400 feet. Within the limestone are numerous concretions locally known as "jicoteas" (turtles) or "quesos" (cheese). These concretions contain fish remains that have been identified as Oxfordian and ammonites that range from Bajocian to Portlandian.[8] Within the chambers of the ammonites there is often liquid or dry asphalt.

In 1935 R. E. Dickerson and W. H. Butt[9] found ammonite-bearing concretions in the thinly bedded Jagua formation which they mistook for the Cayetano formation which it somewhat resembles. Subsequent work has shown that the Viñales limestone and occasionally portions of the underlying Jurassic Jagua formation have been thrust over the Cayetano, with the result that in

[2] "Sierra Maestra of Cuba," *Bull. Geol. Soc. Amer.*, Vol. XLV (1934), pp. 567–619, Pls. 57–85.

[3] *Informe sobre un reconocimiento geologico de Cuba* (Habana: Sec. Agric., Dirección de Montes y Minas, 1938).

[4] L. Rutten, "Geology of the Isle of Pines," *Proc. K. Akad. Wetensch. Amsterdam*, Vol. XXXVII (1934), pp. 3–8.

[5] Barnum Brown and M. O'Connell, "Correlation of the Jurassic Formations of Western Cuba," *Bull. Geol. Soc. Amer.*, Vol. XXXIII (1922), pp. 639–64; J. W. Lewis, "Geology of Cuba," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVI (1922), pp. 533–55.

[6] P. 6 of ftn. 4 (1934).

[7] *Ibid.*, p. 5.

[8] Brown and O'Connell, ftn. 5 (1922).

[9] "Cuban Jurassic," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XIX (1935), pp. 116–18.

these places the Jagua appears to be directly above or part of the Cayetano (Fig. 3).

The formation is known only in the Organos Mountains in the western part of the island. The best-known exposure is in the area known as Jagua Vieja, 3 kilometers east of Constancia and 10 kilometers northeast of the village of Viñales. "Jagua" is, therefore, suggested as an appropriate name for this formation.

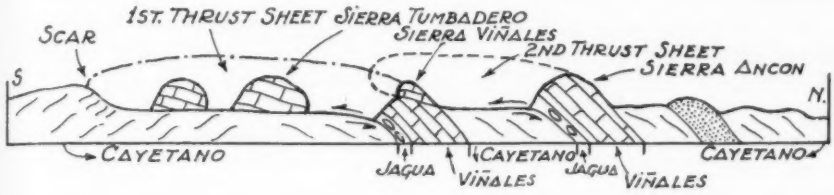

FIG. 3.—Northwest-southeast section through the Organos Mountains. The "scar" on the south marks the south edge of the overthrust.

QUEMADO FORMATION

The next younger formation occurs locally in Santa Clara Province. It is a series of hard, brown, siliceous and calcareous sandstones and hard, brown limestone. A scant, poorly preserved ammonite fauna occurring in this formation has heretofore been identified as Lower Cretaceous. In 1942, R. Imlay[10] described this fauna and determined it as Portlandian Jurassic.

The fauna described by Imlay from La Catalina, Pinar del Río Province, and Loma Camajan, Camagüey Province (loc. 18581), is believed to belong to this formation. Jaworski, as quoted by L. W. J. Vermunt,[11] believes the La Catalina fauna to be Tithonian or more probably Lower Cretaceous in age.

As this limestone has its greatest development near Quemado de Güines in Santa Clara Province, it is given the name "Quemado formation." Fourteen kilometers west of Sagua and directly south of Caguaguas this formation makes up the terrain for a distance of 5 kilometers (3 miles). Here it has a thickness of 4,400 feet.

CRETACEOUS

APTYCHUS BEDS—VIÑALES LIMESTONE

Lying directly above the Quemado formation in Santa Clara and Camagüey provinces are the Aptychus beds, so called for the abundant aptychi or ammonite opercula they contain. This formation is of long longitudinal distribution, occurring in the northern half of Cuba from Pinar del Río to Camagüey, a distance of 720 kilometers (430 miles). Good exposures occur in the eastern end of the Organos Mountains in western Cuba. In Santa Clara Province one of the best exposures is north of Loma Penton, 10 kilometers west of Sagua la Grande. Here 1,300 feet is exposed above the Quemado. The long row of hills 5 kilometers west of Camajuaní, Santa Clara Province, is of Aptychus beds, as is also the greater part of Loma Camajan in eastern Camagüey.

[10] "Late Jurassic Fossils from Cuba," *Bull. Geol. Soc. Amer.*, Vol. LIII (1942), pp. 1417–78.

[11] "Geology of the Province of Pinar del Rio, Cuba," *Geog. Geol. Mededeelingen, Phys.-Geol. Reeks No. 13* (1937).

Throughout its extent this formation is strikingly uniform in character. On the surface it is a fine-grained, brownish, thinly bedded limestone. The strata vary from paper thinness to several inches in thickness. In addition to the aptychi, it contains a few ammonite molds and occasional fish skeletons and scales and rare mollusks. Radiolaria abound in many exposures. Locally throughout its distribution there are thin beds of black chert that replace the limestone.

The Aptychus beds weather to a residual red clay with flat, platy boulders. Where not too greatly reduced by erosion, they form rounded hills. The red soil is comparable both in appearance and in fertility to the red soil derived from the Güines limestone. In fact, the red soil derived from both these formations has been mapped as Matanzas Clay by H. H. Bennett and R. V. Allison.[12] At depth the Aptychus beds are bituminous, shaly, soft marlstone. Their bituminous nature, together with the oil seeps occurring in them and in the overlying formations, has led to the conclusion that this formation contains the source beds of oil and asphalt in Cuba.

In many localities throughout its distribution there are thinly bedded, black, shaly cherts lying below the aptychus-bearing member. Below these and at the base of the formation and equally as spotted in occurrence is a coarse, calcareous sandstone or fine conglomerate. The best-known exposure of the three members of the formation is at Santa Fé near Camajuaní, on the road to Santa Clara in Santa Clara Province. At Cenral Zaza, near Placetas, Santa Clara Province, thin beds of tuff occur in Aptychus beds. M. G. Rutten[13] reports a similar observation.

The typical Aptychus beds do not extend westward beyond San Diego de los Baños in Pinar del Río Province. Here the Viñales limestone appears to occupy the same stratigraphic position. This is a hard, brittle, gray, massive limestone in which fossils have not been found. It forms the mass of the Organos Mountains and weathers in large, steep-sided blocks which are the above-mentioned mogotes (see p. 3) (Fig. 2). A review of the descriptions of the Viñales limestone and the Aptychus beds reveals that the qualities of the two are in distinct contrast. Scarcely a descriptive term of one can be applied to the other, though the two are probably in part equivalent. This as a practical measure warrants the use of two formational names.

The age of the Viñales and Aptychus beds has been a matter of much discussion. Hayes, Vaughan, and Spencer[14] considered the Viñales Paleozoic. E. DeGolyer[15] described the former and ascribed it to the Jurassic on the basis of the ammonites found associated with the mogotes. Later, Brown and O'Connell[16] also considered the Jurassic ammonites as coming from the limestone talus at the base of the Viñales limestone cliffs. J. W. Lewis[17] considered the Viñales to be Jurassic. Dickerson and Butt[18] found an ammonite fauna near

[12] *The Soils of Cuba* (Washington: Tropical Plant Research Foundation, 1928).

[13] "Geology of the Northern Part of the Province of Santa Clara, Cuba," *Geog. Geol. Mededeelingen Phys.-Geol. Reeks No. 11* (1936).

[14] P. 21 of ftn. 3 (1938).

[15] "The Geology of the Cuban Petroleum Deposits," *Bull. Amer. Assoc. Pet. Geol.*, Vol. II (1918), pp. 133–67.

[16] P. 648 of ftn. 5 (1922).

[17] "Geology of Cuba," *Bull. Amer. Assoc. Pet. Geol.*, Vol. XVI (1932), pp. 533–55.

[18] P. 117 of ftn. 9 (1935).

La Catalina, Pinar del Río Province, in what they believed to be Viñales limestone. Subsequent field work has shown that these fossils come from beds probably equivalent to and herein named "Quemado formation" below the Viñales or Aptychus. The fossils are Portlandian in age, according to Imlay.[19] F. Trauth,[20] on the basis of the aptychi, ascribed the aptychus-bearing beds to the Lower Cretaceous Neocomian.[21] Imlay[22] uses the term "Viñales" to include both the typical Viñales limestone and the lithologically distinct Aptychus beds and ascribed it to the Jurassic on the assumption that all the ammonites he describes were from the Viñales formation. But, in fact, the faunas of three formations were described or mentioned in his paper: (1) the Jagua formation, Oxfordian (?), lowest Jurassic which contains ammonite-bearing concretions; (2) the Quemado formation, which furnished the diagnostic fossils of the Portlandian Jurassic; and (3) Aptychus beds which lie immediately above the Quemado formation. The age determination of the Aptychus beds, therefore, remains unchanged and is still open to question.

From the eastern half of the Organos Mountains eastward, the Aptychus beds are generally calcite-veined and much more contorted and sheared than the younger Cretaceous and Tertiary formations, indicating that they were subjected to marked diastrophism prior to the deposition of later sediments. This was the first and the greatest diastrophic event in the history of Cuba of which there is record. In the western 100 kilometers of the island the Viñales underwent the same compression, but it was thrust bodily over younger formations without being sheared except at the base.

PROVINCIAL LIMESTONES

The known Cretaceous record from the Aptychus beds to the Habana formation is very incomplete. A number of limestone lenses occur in a thick tuff series in southern Santa Clara and Camagüey provinces. Some of these are referred to the Provincial limestone; others are younger. A. A. Thiadens[23] described the Provincial limestones as follows: "The Provincial limestones are a light yellow, dark gray, grayish blue, fine to medium grained, mostly microconglomeratic rocks, cut by many small and large, white calcite veins. They are thick bedded but mostly they are thin bedded." The formation carries a rather rich though poorly preserved fauna of caprinids, Nerineidae and an occasional Apricardia, which indicate Cenomanian-Turonian age.

[19] P. 1442 ff. of ftn. 10 (1942).

[20] "Ueber Aptychenfunde auf Cuba," *Proc. Akad. Wetensch. Amsterdam*, Vol. XXXIX (1936), pp. 66–76.

[21] Trauth (*ibid.*) reports that several species of Cuban aptychi were earlier described from the Cape Verde Islands, from the Alpine-Mediterranean region including Spain, southern France, the Alps, the Carpathian Mountains, and Algiers. He has therefore placed the Cuban species in synonomy with them. He mentions that the Cape Verde Island aptychi are from platy limestone (*Plattenkalken*). Dr. E. Jaworski of Bonn University has examined material from the Cape Verde Islands and from Cuba. He stated (verbal communication) that the lithology of the two is the same and that the aptychi are unquestionably Barremian (Lower Cretaceous).

Some years ago an opportunity was presented to examine material collected from Persia by the Anglo-Iranian Oil Company. The thin-bedded, marly limestone, tawny or buff in color with what appeared to be Radiolaria, was a duplicate of the Aptychus beds of Cuba. I was informed that the formation carried aptychi and was ascribed to the Neocomian. There is thus strong evidence that during the Neocomian the Mediterranean (Tethyan) Sea extended from Cuba eastward 5,000 miles to Rumania with the suggestion that it reached Persia, 2,000 miles still farther east.

[22] P. 1435 of ftn. 10 (1942).

[23] "Geology of the Southern Part of the Province of Santa Clara, Cuba," *Geog. Geol. Mededeelingen, Phys.-Geol. Reeks No. 12* (1937).

CAYETANO FORMATION[24]

The Cayetano formation has not been recognized outside Pinar del Río Province. It reaches its greatest development north of the Organos Mountains and west of the meridian passing through Pinar del Río City. Here 34,500 feet[25] is exposed. As far as known, this is the thickest formation in Cuba. It extends around the west end of those mountains and eastward along their south flank, occurs under the mogotes within the Organos Mountains, and occupies the greater part of the northern half of the province. It is exposed as windows where the overthrust Viñales limestone is a more or less continuous sheet, as in parts of the eastern end of the range. The Cayetano is a thick series of very dark greenish sandstones and dark micaceous shales that weather to various tints and shades of red and brown and even white. The weathered-surface exposures bear little or no resemblance to the same beds below the oxidized zone. The Cayetano has been referred to in published reports as a series of schists and phyllites. Schuchert[26] speaks of the (San) Cayetano as metamorphosed strata that make up the basement complex. Lewis[27] calls it the "Pinar schist" and describes it as yellowish, friable, mica schists and reddish shale slates. These terms are quite misleading, as they imply metamorphism. Personal observation witnesses no metamorphism except near igneous intrusions or where the rocks were exposed to local stresses incident to the overthrusting. The only alteration shown by the great mass of Cayetano shales and sandstones is due to weathering.

The Cayetano is largely shale, though there are well-defined sandstone lenses, particularly on the north side of the Organos Mountains. Where the latter are of considerable magnitude they form prominent ridges up to several kilometers in length. Near the base of the formation and rarely higher in it there are a few hard, clastic, or massive limestone lenses. Usually the limestone has a bituminous odor, and occasionally oil seeps are seen.

The Cayetano soils are highly siliceous and, except in a few small areas where the limestone is present, are very poor and but little cultivated. As already stated, the formation supports a scant flora, a notable feature of which is pines and oaks. The oaks have not been noted in Pinar del Río except on this formation or its derivatives. Pines occur both on the Cayetano and on the iron-rich residual, lateritic soils of the serpentines. When supplied with sufficient moisture, the Cayetano soil produces the famed tobacco of Vuelto Abajo.

The age of the Cayetano formation is not satisfactorily known. It lies above the Viñales limestone (Aptychus beds) and below the Big Boulder bed of the Habana formation. DeGolyer,[28] who described it, called it "Cretaceous"; Brown and O'Connell[29] consider it pre-Oxfordian; Lewis [30] called it the "Pinar schists" and considered it pre–Middle

[24] The formation was described by DeGolyer (p. 140 of ftn. 15 [1918]) and given the name "Cayetano." Dickerson and Butt (pp. 116 ff. of ftn. 9 [1935]) referred to it erroneously, using the name "San Cayetano." This error was followed by C. Schuchert and by Imlay (pp. 1421 ff. of ftn. 10 [1942]). (*Historical Geology of the Antillean-Caribbean Region* [New York: John Wiley & Sons, 1935], pp. 410, 495, 515, etc.)

[25] I am indebted to E. N. Pennypacker for this calculation. It was taken from a section from the central part of the Organos Mountains northwest to the coast.

[26] P. 495 of ftn. 24 (1935).

[27] P. 534 of ftn. 17 (1932).

[28] P. 150 of ftn. 15 (1918).

[29] P. 648 of ftn. 5 (1922).

[30] P. 534 of ftn. 17 (1932).

Jurassic. Metcalf, in a discussion of Lewis' paper,[31] said he believed it to be above the Viñales. Dickerson and Butt[32] ascribed it to the Jurassic, believing that the Jurassic ammonite-bearing concretions were indigenous to it. H. M. E. Schürmann[33] places the phyllite (Cayetano) stratigraphically below the Jurassic. Vermunt[34] placed the Viñales and Cayetano together in one formation—the San Andres. This formation also includes the Quemado. Referring to the San Andres, he states: "We take the phyllitic, quartzitic rocks and the limestones to belong to a continual sedimentation cycle in Jurassic to lower Cretaceous time."[35] Imlay[36] quotes Dickerson to the effect that the high fixed-carbon ratio of the bitumen often found in the chambers of ammonites from the concretions presumed to have been taken from the Cayetano formation are an indication of age. This is misleading, as the ammonites in fact come from the Jurassic, and, furthermore, bitumen is merely dried petroleum which in the tightly sealed chambers is often found as a liquid; where evaporation has been possible the volatiles have left, giving a higher percentage of fixed carbon in the residue.

The only fossil remains in the typical Cayetano are small clams resembling the genus *Sphaerium*, which have been found in a few localities, and a few vegetal remains. In the limestone lenses, however, near the base of the formation there are a few Foraminifera. As these have not been studied in detail, nothing can be stated except that the genera appear to be the same as those occurring in the Lime gravel member of the Upper Cretaceous Habana formation. It is these limestone lenses in the Cayetano that Vermont calls the "Mountain facies" of the Habana formation.

TUFF SERIES

A thick series of tuffs, agglomerates, and flows makes up a large portion of the Cretaceous column. These range from a few thin beds in the Aptychus to the top of the Cretaceous (see Table 1) and in Oriente Province to the Middle Eocene. The series has its greatest development in southern Santa Clara Province in central Cuba. Here it forms a belt 120 kilometers (70 miles) long by 25 kilometers (15 miles) wide and, according to Thiadens' estimate,[37] has a thickness of 8,000 meters, though it now is believed to be much thicker. In Matanzas Province more than 2,000 feet is known; in Habana 5,000–6,000 feet; and north of the Organos Mountains in western Cuba, 1,300 feet is exposed. In Camagüey Province the thickness is comparable to that of Santa Clara. The tuffs have been encountered in oil wells in Habana and Matanzas provinces.

Except in central Cuba, the tuffs are not everywhere continuous. In Habana, for example, there is a tuff lense entirely surrounded by normal marine sediments, indicating that it is the product of a single volcano.

The ejected material consists of tuffs, agglomerates, and flows. These have been excellently described by Thiadens,[38] who named the formation. The lithology of the series is of the intermediary type, and attention may be called to the fact that none of the known examples is suf-

[31] *Ibid.*, p. 553.

[32] P. 117 of ftn. 9 (1935).

[33] "Massengesteine aus Cuba," *Neues Jahrb. Beilage-Band 70*, Abt. A (1935), p. 336.

[34] P. 7 of ftn. 11 (1937).

[35] *Ibid.*, p. 11.

[36] P. 1422 of ftn. 10 (1942).

[37] P. 12 of ftn. 23 (1937).

[38] *Ibid.*, p. 12.

ficiently basic to be the parent-rock of serpentine. This suggests that the extensive serpentines of Cuba are genetically unrelated to Cretaceous igneous activity.

The widespread occurrence of Radiolaria and Foraminifera in the tuffs and agglomerates indicates that a large portion of them was deposited in the sea. Many lenses of marine limestone, varying from a few feet to several hundred, are indicative of the same origin. Several of these lenses are referred to the Provincial limestone described above.

HABANA FORMATION[39]

This widely distributed formation occurs in all the provinces of Cuba. It carries an abundant and well-preserved fauna of foraminifers, corals, mollusks, and echinoids that is Maestrictian, Upper Cretaceous, in age. The Habana formation is well exposed along the axes of both the Habana-Matanzas and the Madruga anticlines. In central Cuba several hundred square miles of Upper Cretaceous deposits are exposed on the Rodas anticline (see p. 25).

There are three members in this formation in the northern half of the three western provinces. The oldest is termed the "Lime gravels," composed of loosely consolidated limestone pebbles which vary in size from coarse sand to half an inch in diameter. The gravels contain orbitoids, rudist fragments, and, rarely, echinoids. Within the pebbles themselves there are often alveolinellid Foraminifera which are also considered Upper Cretaceous in age.

The second member is the "Cone sandstone," so called from the cone-shaped concretions that form under subaerial weathering. These cones develop in an inverted position with the base parallel to the bedding plane. This member is a light-gray, uniformly fine-grained, calcareous sandstone with scattered chlorite grains and lime cement. Both the Lime gravel and Cone sandstone are well exposed at San Francisco on the Central Highway, 12 kilometers southeast of Habana. Locally the Cone sandstone varies laterally to white marls. Its hardness makes it a valued stone for building and road purposes. Topographically it forms hills.

The third and youngest member of the Habana formation is the "Big Boulder bed," named from the habit of weathering to a residue of large boulders that makes its identification in the field possible even at a distance. The boulders are in part from conglomerates in the formation and in part from the disintegration of the limestone beds. The excellent Upper Cretaceous molluscan, coral, foraminiferal, and echinoid fauna with few exceptions is confined to this member. Very rarely large fragments of silicified wood in the form of rounded boulders are encountered. Though this member is well represented in both the large anticlines of western Cuba, the fauna is very largely confined to the southern one. On the other hand, tuffs are by far the more abundant in the northern structure, where fossils are few.

The three members occur together at Cantarana, 9 kilometers east of Madruga, Habana Province. They were, however, not recognized in oil wells located at a considerable distance south of their surface exposures in Habana and Matanzas provinces, but instead there was a dark-gray shale that is their equivalent. On the other hand, Big Boulder bed foraminifers and Cone sandstone

[39] The Upper Cretaceous and Tertiary of Habana and Matanzas provinces have been studied and ably described by Ing. Jorge Brodermann, "Determinación geológico de la cuenca de Vento," *Tercer Congreco Nacional de Ingenieria* (1940), pp. 8–28.

were encountered in a well near the north coast a short distance east of Habana. The data seem to indicate that the three members of the formation were not deposited as such except in the general area mentioned.

The two lower members of the Upper Cretaceous are confined to the three western provinces. The Big Boulder bed is the sole representative of the Upper Cretaceous occurring in all the provinces. The three members are shallow-water deposits with the exception of the white marls, which are believed to be the lateral facies of the Cone sandstone. In southern Santa Clara and Camagüey provinces, both the Middle and the Upper Cretaceous are tuffs with clastic limy lenses.

TWO PHASES OF UPPER CRETACEOUS

There are two phases of the Upper Cretaceous (see Fig. 1), as pointed out by M. G. Rutten.[40] The marls, sandstones, limestones, conglomerates, and igneous debris already mentioned as occurring in Pinar del Río, Habana, Matanzas, and the southern half of Santa Clara and Camagüey provinces constitute the southern phase as described by Rutten. The name "Habana formation" usually refers to this phase. The northern phase is limited to the northern half of Santa Clara, Camagüey, and Oriente provinces. This latter phase is almost a pure limestone.

JARONÚ LIMESTONE

The best-defined exposure of the northern phase is on the lands of the Jaronú sugar mill in Camagüey Province, where a section of 27,000 feet was measured. Accordingly, the name "Jaronú limestone" has been applied to this phase. The presence of Barrettia, caprinids, and Nerinea low in this section indicates that some of the northern phase is older than Upper Cretaceous.

LIMESTONE BRECCIA

Near the top of the northern phase in the vicinity of Camajuaní is a thick limestone conglomerate carrying large, sharply angular fragments of Aptychus limestone and chert. What appears to be the same conglomerate appears near the top of the Jaronú section. The angular boulders suggested the name "Limestone breccia" for this member of the Jaronú limestone. This member carries Foraminifera of the species occurring in the southern phase of the Upper Cretaceous.

Small chloritized fragments of tuff also occur in the Limestone breccia. These are the only evidence of Upper Cretaceous volcanic activity in the northern phase.

Although at least in part the same age, the northern and southern phases were deposited under entirely different conditions of sedimentation and evidently in widely separated areas. There is some 27,000 feet of limestone lying above the Aptychus beds on the north and a comparable amount of tuffs occupying the same stratigraphic position to the south, and yet the two are separated by a distance of only 5–10 kilometers (see Fig. 5). It appears that the southern representative was pushed northward during the extensive overthrusting that will be discussed later.

The Big Boulder bed presents several problems. The boulders from the conglomerate phase are of types whose parent-formation is nowhere known in Cuba. Where similar types of rocks do occur, they are several hundred kilometers distant and belong to periods of igneous activity long subsequent to the Creta-

[40] Pp. 21, 23 of ftn. 13 (1936).

FIG. 4.—Viñales Valley looking southwest. The cliff is the south side of Sierra de Viñales. The portion below the white line resembling talus is the remnant of an earlier overthrust sheet of Viñales limestone; that above is a later overthrust sheet. See section, Fig. 3. (Photograph by T. E. White)

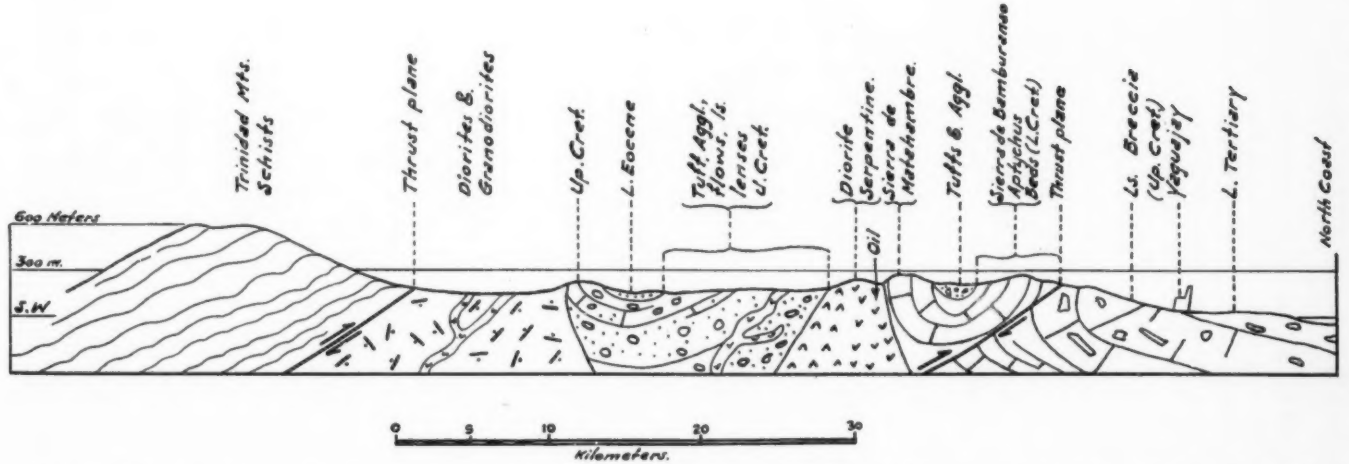

FIG. 5.—Northeast-southwest section (*A*–*A'*) through eastern Santa Clara Province. Stratigraphically the Limestone breccia of the north phase and the tuffs of the south phase both directly overlie the Aptychus beds. Overthrusting has reversed this position along the north fault and has brought the tuffs of the south phase to within 5 kilometers of the north limestone phase. Late in 1943 a light oil was encountered at shallow depth along the serpentine-Aptychus beds contact in the Sierra de Matahambre.

ceous. There are granites, granodiorites, andesites, rhyolites, basalts, and boulders of sedimentary origin, such as slates, quartzites, schists, and gneisses, whose sources are so hidden that they are but themes for speculation. The boulders in the Cretaceous exposures in the southern or Madruga anticline average somewhat larger than similar boulders in the northern anticline. This has suggested that the mass supplying them lay to the south.[41] Evidence in line with this suggestion is found in the similarity of the Upper Cretaceous shore fauna of Jamaica and Cuba. This in many cases amounts to identity of species. Such similarity in a distinctly shallow-water fauna is difficult to explain if it be assumed that during Cretaceous times Jamaica was separated from Cuba by an expanse of deep water as it is today.

The Upper Cretaceous fauna is southern European in its affinities and distinctly not North American. It is a part of the Caribbean fauna which in turn belongs to the Tethyan or Mediterranean realm of the Old World.

TERTIARY

CAPDEVILA FORMATION, PALEOCENE

The Capdevila formation is a thick series of shales, sandstones, and a few conglomerates which is rather widely distributed in western Habana and eastern Pinar del Río provinces. It weathers to an ochreous brown soil that is rather poor for agriculture.

The Capdevila is folded with the Upper Cretaceous, and in some localities its lithology recalls the Big Boulder bed. Its scanty fauna is confined to Foraminifera and Radiolaria. Some of the Foraminifera are Midway Eocene in age. As pointed out by Brodermann,[42] this is probably a transitional formation. It is well exposed at Capdevila, 10 kilometers south of Habana.[34]

EOCENE

P. J. Bermúdez[44] described the white marls on the University of Habana campus as Lower Eocene and named them the "Universidad de la Habana formation." In its typical exposures in Habana this formation is a white- or cream-colored marl less than 100 feet in thickness.

Deposits ascribed to the Middle Eocene occur in all the provinces of Cuba, the greatest development being in Habana Province in a part of the Madruga anticline known as the Bejucal uplift. Marls, sandstones, and fine-grained conglomerates are the principal elements. These deposits yield excellent foraminiferal faunas representing the Cook Mountain and Mount Selman series of the Claiborne group of the Gulf Coastal Plain. In Oriente Province the thick basaltic flows between Palma Soriano and Santiago de Cuba are Middle Eocene in age. It is possible that some deposits previously referred to the Middle Eocene may be a shallow-water phase of the Upper Eocene.

The Príncipe formation[45] is the principal formation in the Upper Eocene. It is a white- or cream-colored marl that closely resembles the Universidad. It has a large and well-preserved foraminiferal fauna with a few echinoids, echinoid spines, corals, crinoid stems,

[41] R. H. Palmer, "Geology of Habana, Cuba and Vicinity," *Jour. Geol.*, Vol XLII (1934), p. 140.

[42] P. 23 of ftn. 39 (1940).

[43] Palmer, p. 132 of ftn. 41 (1934).

[44] "Estudio micropaleontologico de las formaciónes de las cercanías de la Habana, Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vol. XI (1937), pp. 153–79.

[45] Palmer, p. 132 of ftn. 41 (1934).

and barnacles. At the type locality in Habana City the marls are about 70 feet thick but thicken to the south. Both the Universidad and the Príncipe were deposited in water 100 or more fathoms deep, and both retain much fossil salt. The Príncipe formation weathers to a loose pink or brownish soil that, with sufficient moisture, is rather productive.

OLIGOCENE AND MIOCENE

TINGUARO MARL

The oldest known Oligocene in Cuba is found in the Colon anticline in Matanzas Province. It is a thick series of bluish-gray marls that weathers to a buff or tawny soil which is very compact and impermeable to water. It is poor agricultural land. Good exposures of these marls occur on the lands of the Tinguaro sugar mill and suggested the name for the formation. The marls yield an excellent foraminiferal fauna, part of which was described by D. K. Palmer and P. J. Bermúdez.[46] The Tinguaro marls are believed to be in part the deep-water equivalent of the zone of the large Lepidocyclina that occurs directly above the Eocene in many widely separated localities in Cuba. *Lepidocyclina undosa* and *L. favosa* are two characteristic species of the shallow-water facies. Though these species are referred to the Middle Oligocene or even Miocene in the Gulf States, they occur near the base of the Oligocene in Cuba.

The echinoid fauna of the Upper Eocene and Lower Oligocene, like that of the Upper Cretaceous, has striking Old World affinities. So great are the similarities that many species from Cuba and Egypt are indistinguishable.

The remaining divisions of the Oligocene and Miocene are marls and limestones. For the most part they weather to a residual brown or red clay that ranks high as cane land.

GÜINES LIMESTONE

One of the well-recognized formations of Cuba is the Oligo-Miocene Güines limestone. This is the most widely distributed formation in the island. It is nearly coextensive with the fourth and sixth physiographic provinces. At the surface the formation is a hard, brittle, white or pinkish limestone, in places packed with molluscan and coral molds; a few feet below the surface it is soft, fragmental, and loosely consolidated. Where elevated a few hundred feet, it forms jagged hills such as flank the Habana-Matanzas anticline on the south. The Güines limestone is very porous and easily channeled, with the result that the drainage of this terrain is almost entirely underground. Collapse of cave roofs has formed sinkholes, and in elevated areas a slump or karst topography has resulted. Good examples of this topography are at Jamaica, 25 kilometers southeast of Habana, and in the irregular hills between Limonar and Coliseo in Matanzas Province.

These hills of Güines limestone, though nearly barren of soil, support a dense growth of bushes, vines, and trees. In the underground streams and caves there lives a diversified blind fauna of fishes, spiders, crickets, and shrimps.

The residual soil from the Güines limestone is a red laterite highly prized for agricultural purposes. As stated above, it makes the best cane land in Cuba. The formation of laterite is a tropical or subtropical process or weathering. In the temperate zones the products of weathering are carbonates, silicates, oxides, and hydrous silicates. In

[46] "An Oligocene Forminiferal Fauna from Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vol. X (1936), pp. 227–71.

the tropics the process takes another course or continues to a more complete oxidation, and decomposition of the silicates and the end products are iron and aluminium hydroxides. These insoluble products accumulate as residual soil known as laterite. Laterite in Cuba is derived from both limestone and serpentine. Over large areas in Camagüey and Oriente provinces laterite derived from serpentine has an iron content sufficiently high to make it a valuable iron ore. On the surface of the laterite numerous small pellets of hematite called "perdigones" (shot) have formed. So abundant are these in places that they give a distinctly purplish color to the soil. Under conditions not well understood these perdigones become imbedded in a matrix of limonite, the whole forming a barren soil known as mocarrero.

PLIOCENE AND PLEISTOCENE

Deposits of either of these epochs have not been definitely recognized. Bordering the coast in many places is a narrow collar of hard limestone into which the sea has cut terraces. The city of Habana is located on these marine terraces. Above one of the cliffs is Morro Castle, a well-known landmark of Habana. This limestone contains a few molluscan species and many unidentifiable molluscan and coral molds, but whether the deposits are Pliocene or more recent is not known.

IGNEOUS ROCKS[47]

INTRUSIVES—BASIC

Both intrusive and extrusive igneous rocks occur in Cuba. They in turn are both acid and basic. The basic rocks are for the most part serpentinized intrusions of peridotite, troctolite, or dunite and, with few exceptions, are confined to the northern half of the island. Examples are the serpentine intrusions in the Organos Mountains, the Habana-Matanzas anticline, the Madruga anticline, the Santa Clara overthrust area, central Camagüey, and the disturbed areas in the northern and eastern parts of Oriente Province.

There is no agreement on the time when the serpentine masses were intruded. M. G. Rutten[48] believes them to be pre–Upper Cretaceous. Other unpublished opinions place them in the Upper Cretaceous, Middle Eocene, and even post–Upper Oligocene. The views vary because of the assumption that the serpentines are of the same age, which is not the case. Most of them are intrusive within the Upper Cretaceous terrain, where they have been exposed by erosion. Such are, therefore, post–Upper Cretaceous. Dr. Thomas Thayer, in a personal communication, reports serpentine fragments in the Lower Cretaceous Aptychus beds, implying some pre–Lower Cretaceous serpentine. In western Oriente Province fragments of serpentine occur in the Upper Cretaceous showing a pre–Upper Cretaceous intrusion. The improbability of the Upper Cretaceous age of the serpentine in western Cuba has been pointed out (p. 11). South of Camagüey City the Upper Cretaceous limestone is marmorized near the serpentine contact, indicating a

[47] Schurmann (pp. 339–42 of ftn. 32 [1935]) divides the igneous rocks of Cuba into three classes: (*a*) The intrusions related to the intensive orogeny (Hochorogenese), one of which he places in the Upper Cretaceous. These are the serpentines (syntectonic) and the granodiorite (post-tectonic). (*b*) Older pre-Cretaceous intrusives and extrusives of the Tuff series. These are porphyries and diabases. In contrast to the orogenic intrusions he refers these to geosynclinal types. (*c*) Post-orogenic serpentines, porphyrites, and intrusions of more acid rocks into serpentines and, in southern Oriente, flows of basalt and andesite. These may be Middle Eocene.

[48] P. 13 of ftn. 13 (1936).

later date for that intrusion. In Santa Clara Province a dike is known to cut the Eocene. In Matanzas Province there are serpentine outcrops in an Upper Oligocene limestone terrain. The limestone immediately around the serpentine is marmorized in a zone a few feet wide, while beyond this it is entirely normal. Around the intrusion the Upper Tertiary limestone has dips up to 30°, whereas ordinarily these limestones are flat or, where they border low, post-Oligocene structures, they have dips of 5° or, at most, 8°. In these localities the intrusions appear to be late Tertiary in age. Obviously, there have been several different times of intrusion.

The serpentine-derived soils support a very scant vegetation and are probably the poorest agricultural soils in Cuba. Palma cana (*Sabal parviflora* Bec.), Yuraguana (*Coccothrynax miraguano* Bec.), and Jata de Guanabacoa (*Copernicia macroglossa* C. Wendl.), while not entirely confined to the serpentine, are characteristic of it. However, the lateritic soils derived from iron-rich serpentine support valuable pine forests. Analysis of the soils from the iron-rich and the iron-poor serpentines show a notable percentage of potash in the former and but traces in the latter. The presence of this essential ingredient in the iron-rich serpentine may in part account for its heavy pine growths.

The solid stand of pines is a notable exception in tropical forests. In general, a tropical forest is an indiscriminate mixture of numerous species. Except in high altitudes where temperate conditions prevail, solid stands, like an oak or maple or beech forest of the north, do not occur. It seems strange that these low hills should supply the proper conditions for the pines. The rule seems to be that in the tropics abundant species with few individuals comprise the forests; in the north the reverse prevails. Curiously, the same rule applies to marine molluscan faunas.

The serpentines of Cuba are, however, of economic importance for their local mineral content. The iron-ore deposits that accumulate in the residual laterite from serpentine have already been mentioned. The iron deposits of Mayari and Moa districts in Oriente, in San Felipe in Camagüey, and on Loma Cajalbana in Pinar del Río are examples. The Mayari deposits contain about 1 per cent nickel, which is at present (1944) being exploited. Valuable deposits of chrome also occur in serpentine. They were originally magmatic segregations in the dunite or peridotite, the parent-rocks of the serpentine. There are a number of these deposits scattered over Cuba, the most important being in Camagüey and northern Oriente provinces.

In addition to the serpentine masses, there are many smaller intrusions of diorite, gabbro, and a few of granite and granodiorite in the northern half of the island. In the eastern part of Oriente altered intrusions associated with serpentines form the core of the mountains. Around this core and dipping away from it is a collar of sediments. The intrusions are pre-Tertiary, and the attitude of the Tertiary sediments is due to the late Tertiary folding.[49]

INTRUSIVES—ACID

The southern half of the island has fewer intrusions. On the north side of the Trinidad Mountains in southern Santa Clara Province there are two large granite and granodiorite intrusions whose

[49] For the data and comments on the geology of eastern Oriente I am indebted to Dr. Thomas Thayer.

weathered debris produces a loose, highly siliceous soil similar to that of the Cayetano and, like that soil produces high-grade tobacco. Acid intrusions border the large serpentine mass on the south in southeastern Camagüey Province.

In western Oriente there is a large intrusion of granodiorite and granite occupying an area of 400 square kilometers. In central Camagüey granodiorite and granite are exposed in patches over an area of 250 square kilometers near Florida. In the latter area an attempt was made to remove a supposed boulder, but the project was abandoned when 6 or 8 feet of excavating revealed that the boulder became larger at depth. Instead of being a boulder, it was in reality a knob from a large mass of granodiorite lying buried under the surrounding sediments. The excavation was made in the Habana formation chalk and marl, and these showed no trace of metamorphism along the contact with the granodiorite, indicating the latter to be pre–Upper Cretaceous. A similar granodiorite occurs at Ciego de Avila in western Camagüey, and there are like patches in eastern Camagüey.

Field evidence indicates that the granodiorite intrusions in central and eastern Cuba are approximately the same age. The data in the preceding paragraph clearly show that the Camagüey granodiorite precedes the Habana formation. What precedes the granodiorite, however, is not so clear. Thiadens states: "The contact phenomena in the Tuff Series near the contact with the diorite prove that the Tuff Formation is older than the diorite."[50] L. Rutten[51] states that the granodiorites are post-Tuffs and probably pre-Emscher (Lower Senonian). Both calculations are based on the assumption that the tuffs are Cenomanian-Turonian-Emscher, which, as has been pointed out, is true only of parts of the Tuff series. From the data at hand the only statement that can be definitely made as to the age of the granodiorites is that they are later than some of the tuffs and are older than the Habana formation.

It will be noted that the intrusive rocks in the southern half of the island do not extend west of about the central meridian and that they are acidic types. In contrast, the intrusions in the northern half occur throughout the length of the island and are basic.

EXTRUSIVES

Extrusive rocks occupy a very small portion of the Cuban terrain. Only two late Pleistocene or Recent unburied flows of any importance are known. One is a comparatively recent flow that covers an area of approximately 25 square kilometers in central Santa Clara Province. The other is an andesitic flow of some 200 square kilometers in Oriente and adjacent parts of Camagüey. In western Camagüey there are two small basaltic cones.

The Cretaceous igneous activity has already been mentioned, and the character of the ejected material and its general distribution discussed. The Cretaceous tuffs, though occupying but a small percentage of the area of Cuba, do in the aggregate amount to many thousand hectares. The tuff-derived soils are for the most part poor and are avoided by agriculture.

There was minor Eocene volcanic activity in the provinces of Matanzas and Oriente, but it was of little importance except for the thick basaltic series that

[50] P. 12 of ftn. 23 (1937).

[51] "The Age of the Quartzdiorite and Granodiorite Rocks in the West Indies," *Geologie & Mijnbouw*, Jaargang No. 5 (1939), p. 129.

forms the greater part of the Sierra Maestra in southern Oriente. Taber[52] estimates the Cobre formation, which is largely made up of these flows, to be over 4,500 meters, and "may be as much as 6,000 meters," in thickness.

No Oligocene or Miocene volcanic rocks are known in Cuba.

STRUCTURE

No statement can be formulated to cover the general structure of Cuba. Past attempts to generalize have given impressions that are erroneous. The position of Cuba on the margin of the great Tethyan belt has subjected it to tectonic forces operating both on the American continent and in the Tethyian zone. This, together with its size (1,200 kilometers long), precludes any possibility of a unit structure throughout the entire island. It has, on the contrary, been broken into blocks somewhat smaller than those on the continent which constitute major structural units. An acquaintance with these major units is sufficient to form an idea of the general anatomy of the island. An account of the minor structures would confuse rather than clarify the general picture. The account will therefore be confined to the major structures as far as known, starting at the western end of the island. These structures are located on the map (Fig. 1).

Occupying nearly the entire length of Pinar del Río Province in a strip 4–10 miles wide is the Pinar overthrust. Here the Jurassic and the Viñales limestone that are normally below the Cayetano are thrust southeastward over this formation (Figs. 2 and 3). The dissected, overthrust sheet of Viñales limestone forms the greater part of the Organos Mountains. The overthrusting was more intense in the eastern end of the range, where it was of the order of 10 miles, diminishing toward the southwest and, at the end of the range, dying out.

The hard Viñales and Jurassic limestones advancing over the soft Cayetano plowed deeply and crushed and contorted the shales before them. After the movement ceased, the front of the limestone sheet retreated as a result of erosion, leaving a valley between the limestone mass on the north and the wall or scar in the Cayetano on the south gouged by the overthrust front. North of Pinar del Río City on the Viñales road the Cayetano wall or overthrust scar is 150 feet high, and the shale beds in the base are crushed and contorted (Fig. 3).

The overthrust was not the simple case of a limestone sheet thrust upward to the surface along a straight line and then southward over the Cayetano. Instead, the overthrust mass broke into segments that came to the surface en echelon along a general line. Examples are the Pan de Guajaibon, about 2 miles north of the general line, and the Sierra Quemado, which is 5 miles south of it. Nor is there everywhere only a single overthrust in a given segment. There are cases of two and even three imbrications. A notable example is the segment containing the two parallel ridges, Sierra del Ancon on the north and Sierra de Viñales on the south. The overthrust apparently started along the southern ridge. This was followed by a second slice on the north which passed over the first. Erosion has reduced the two, leaving the front of the second mass as a steep cliff above the first, whose gentler incline has the appearance of a talus slope (Figs. 3 and 4).

The overthrust structure has been complicated by contemporaneous and possibly minor subsequent folding. This has left the Organos Mountain area

[52] P. 577 of ftn. 2 (1934).

folded in a broad anticlinal structure along the central part of which lies the Pinar overthrust (Fig. 3). The entire column from the Jurassic to the Miocene participated in this folding. The name "Pinar anticline" is proposed for this extensive structure.

The Cayetano, very probably, and possibly the Habana formation capped the Viñales limestone during the overthrusting, but they have since been eroded from the overthrust sheet, leaving no trace of their former presence. Erosion has dissected the limestone sheet and cut it into blocks with nearly perpendicular sides varying in size from small hills to masses of several square kilometers often 500 feet high. These isolated blocks are the "mogotes," the most striking feature of the Viñales landscape, as already stated (Fig. 2).

The pressure causing the overthrusting was from the northwest (see Fig. 1). The configuration of Cuba suggests a possible correlation between several features. Pinar del Río Province has a bearing of N. 70° E., and the adjacent part of the island an east-west bearing, a difference of 20° (see Fig. 1). The 1,000-fathom line of the Gulf of Mexico makes a deep re-entrant off the north coast of Pinar del Río. Southeast of the province is the Isle of Pines, and between it and the mainland are shoals. This combination of features suggests that pressure from the northwest, using western Habana Province as a pivot, moved the western end of the island to the southeast through an arc of 20°. In the northern half of the Isle of Pines the structural lines lie in a north-south direction. This does not oppose the above suggestion. In the southwest quarter of the island the Sierra la Cañada and Cerros del Monte have a strike of N. 55° W. and in the southeast quarter strike east-west with a dip of 10° to 15° north. This is the general attitude of the schists and phyllites of the area. Late movement from the southwest would explain this marked change in the latter structural lines.[53]

A second major structural unit lies in the provinces of Habana and Matanzas. Here two large anticlines or anticlinoria, with an intervening syncline, are the principal features. These lie in an east-west direction. The northern structure, called the Habana-Matanzas anticline, extends from Matanzas City westward to Habana, a distance of 90 kilometers (55 miles). At Habana the structure passes under the Lower Eocene Capdevila formation and continues into Pinar del Río Province. Along the axis of the structure erosion has removed the Tertiary capping and exposed the underlying Cretaceous in a belt 10 kilometers (6 miles) wide except about midway between Habana and Matanzas, where a narrow saddle of Oligocene remains. On this high saddle the Hershey sugar mill is located. The Cretaceous is composed of soft shales, sandstones, and tuffs that are easily eroded. The Oligo-Miocene, on the other hand, is a hard limestone that resists erosion. The resulting topography is a broad valley with a Cretaceous floor flanked on either side by steep Upper Tertiary cliffs. Prominent portions of this wall of cliffs have specific names, as Escaleras de Jaruco, Sierra Camerones, El Palenque, and Pan de Matanzas. As

[53] This suggestion is in keeping with B. Willis' ("Isthmian Links," *Bull. Geol. Soc. Amer.*, Vol. XLIII [1932], p. 927) theory of sinking basins (in this case the Gulf of Mexico) and rising and expanding borders. Schuchert (pp. 37, 368, 400, 496 of ftn. 24 [1935]) mentions specific application of this theory to the area in question. On the other hand, this theory would recognize the overthrusts toward the north in central Cuba as overthrusts from the Yucatán Basin (Antillean Sea of Suess and Schuchert) of the Caribbean Sea.

already stated, many serpentine intrusions occur along the valley. The east end of the valley is drained by Yumurí River and is known as the valley of the Yumurí. The river has cut through the eastern end of the anticline near Matanzas City, forming the picturesque and well-known Yumurí Gorge.

Paralleling the Habana-Matanzas anticline and lying 20 kilometers to the south is the Madruga anticline named for the town located near the middle of the structure. This structure extends from central Matanzas westward through Habana Province and into Pinar del Río Province nearly to the Organos Mountains, a distance of 150 kilometers (90 miles), where it flattens out and disappears. The folding was less intense in the Madruga anticline than in the structure to the north, with the result that the Cretaceous is exposed in a few places only. Elsewhere the Eocene forms the surface along the axis, and in Pinar del Río, where the structure dies out, only the Oligocene is exposed.

Between the two major anticlines is the Almendares–San Juan syncline, named from the two rivers that drain each end of the structure. Near the eastern end the synclinal axis turns to the northeast around the eastern end of the Habana-Matanzas anticline and passes under the water. This submerged portion forms Matanzas Bay.

Santa Clara Province forms a third geological unit. It is characterized by overturned folds, overthrusts, and intrusions. There are three principal structural features in this province: the Cordillera along the north coast, the Santa Clara intrusion in the central part, and the Trinidad Mountains in the southern part.

There are many minor structures in Santa Clara that are more or less subsidiary to the major features. A description of these, however, belongs to detailed accounts and is not within the scope of this paper.

The Cordillera is a series of overturned folds and overthrusts. The force causing these structures was directed toward the north and northeast. The Middle Eocene is the youngest formation observed to have participated in the folding of the Cordillera. A small overthrust of Lower Cretaceous over Middle Eocene occurs 5 kilometers west of Sagua la Grande. The folding is, therefore, late Middle or early Upper Eocene in age. There are several intrusions along the Cordillera, the largest being in the east end.

The Santa Clara intruded zone, in the central part of the province, is a complicated series of rocks ranging from serpentines to granites. The details of this zone and the relationships of the various intrusions have not been worked out.

The Trinidad Mountains (see Figs. 1 and 6) in the southern part of Santa Clara Province is a thick block of schists overthrust from the south and lying on granite and granodiorite. The mass is 80 kilometers (50 miles) wide by 30 kilometers (20 miles) long in a north-south direction. The granodiorites are exposed along the north side of the mountains and are separated from the schists by a highly sheared fault plane (Fig. 5). The main mass of the schists has a uniform south dip. On both the east and the west ends of the mountains the tuffs, Upper Cretaceous limestone, and Tertiary strike north-south and dip away from the schists (Fig. 6). Between the sediments and the schists are wide shear zones. Farther to the north these formations resume the east-west direction in accordance with the general grain of the country.

Thiadens,[54] in a brief discussion of the Trinidad Mountains, considers the possibility of their being an overthrust mass but believes that "the schist-formation is an autochthonous complex."

to the similarity of the Mediterranean and Caribbean regions.

Reference to the map (Fig. 1) suggests a possible correlation between the overthrust features and the topography of

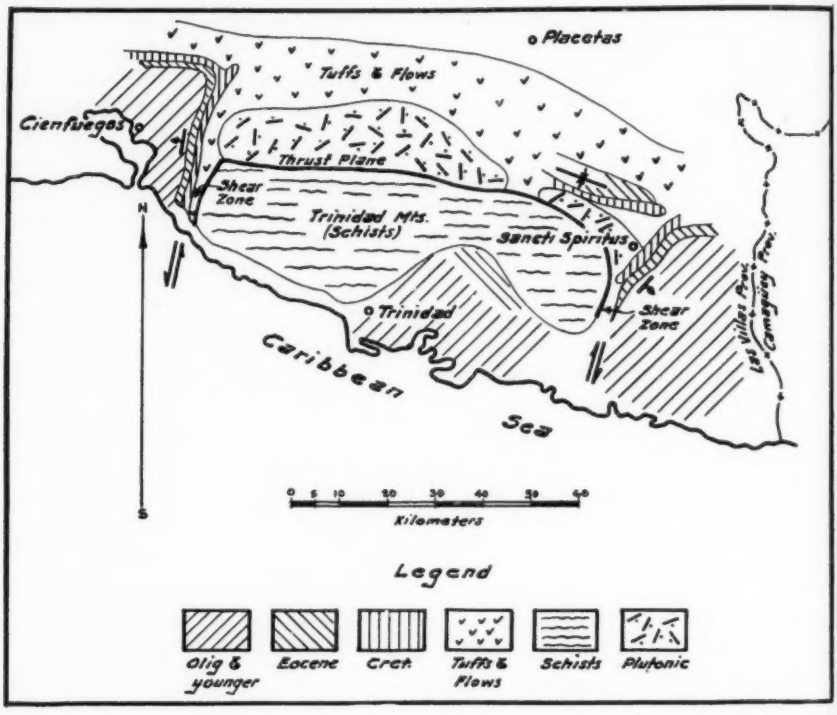

FIG. 6.—Plan of Trinidad overthrust. The Trinidad Mountains are a mass 80 kilometers wide bounded on the east and west by north–south-striking Cretaceous and Tertiary. The mass was pushed northward during late Upper Eocene. North of the mountains earlier movement in late Middle Eocene caused folding in the tuffs, and still farther north in the Cordillera it caused overturning and overthrusting. See Fig. 5.

The overthrust features of central Cuba are suggestive of the Alpine structure of southern Europe with the Trinidad overthrust analogous to the alpine nappes. The Caribbean structures, however, were less intensive and on a much smaller scale. L. Rutten[55] calls attention

the adjoining sea bottoms to the north and south. The 1,000-fathom line on the south side of Cuba makes a detour of 60 kilometers (35 miles) to the north as it passes Santa Clara Province. North of this detour on the mainland are the Trinidad Mountains, followed by a second overthrust zone (Fig. 5). Off the north coast is Cayo Sal Bank. This combination may be viewed as a segment of

[54] P. 48 of ftn. 23 (1937).

[55] "Over de tektonische positie van West Indie," *Natuurwetensch. Tijdschr.* Vol. XVIII, No. 2 (1936).

the surface that was pushed northward, bringing the deep water near the south coast and causing telescoping of the land, a part of which was taken up by the overthrusting on the mainland and a part by the elevations forming the shoals of Cayo Sal Bank. The slight curve in the north coast of Santa Clara and the direction of the overthrusting on the mainland fit into the picture without alteration. According to this suggestion, the Trinidad Mountains were pushed from their former position east of the Isle of Pines northward to their present location, a distance of 50 kilometers (30 miles). Overthrusting on the north side of the province thrust the Aptychus beds over the Upper Cretaceous Limestone breccia and brought the south sandstone-shale-conglomerate-tuff Upper Cretaceous phase in close proximity to the northern limestone phase (see section, Fig. 5). It will be noted that the pressure here was directed to the north and northeast (the *Vergenz* of Stille) in contrast to western Cuba, where it was toward the southeast. In the former case it came from the Caribbean Sea and in the latter from the Gulf of Mexico (see p. 22).

In this connection José Isaac Corral[56] presents a noteworthy theory that is an application of the theory of Continental Drift. His thesis is that the Greater Antilles were formerly adjacent to and a part of Colombia and Venezuela and that during the Upper Miocene they were detached and drifted northward to their present position. This theory may find some support in the overthrusts and overturned folds directed toward the north in Santa Clara Province.

In the southwest corner of Santa Clara Province there is an area outside the overthrust zone. A low, broad, east-west fold known as the Rodas anticline exposes the Cretaceous for a distance of 60 kilometers. Here and in southern Camagüey are the rare places in Cuba where the Upper Cretaceous may be seen lying flat or nearly so.

In Camagüey Province no major structure can be delimited in its entirety. The western half of the province is a plain covered by flat-lying Upper Tertiary limestone. In the north-central part there is an immense structure in which 27,000 feet of Middle to Upper Cretaceous limestone (Jaronú) with a southwest dip has been measured. This structure passes under the Tertiary both to the northwest and to the southeast, and the north flank is under the Bahama Channel. Whether the north side is the limb of an anticline or is faulted off is not known.

In the northern part of western Camagüey there are several structures that bear strong evidence of being salt domes. In general, they have the form of domes; in two places there are large deposits of gypsum of the salt-dome type from which the Tertiary deposits dip. Salt springs occur associated with the gypsum. At present the general area is being investigated by two of the large oil companies.

In eastern Camagüey the most important structure is the large basic intrusion on which Camagüey City is located. This is bordered on the north and on the southeast by rhyolites and diorites and on the south and west by tuffs.

In Oriente Province the major structures are known only in part. The dominant structure in the south is the large and highly complicated monoclinal fold that forms the Sierra Maestra. The basalt and associated tuffs in this fold dip northward from the long system of

[56] "La Union de Cuba con el continente Americano," *Rev. Soc. Cubana de Ingenieros*, Vol. XXXIII (1939), p. 679.

faults that bounds the Bartlett Deep on the north. North of this is the broad syncline of the Cauto Valley. This may be conveniently referred to as the Cauto syncline. This structure extends northward to the intruded zone at Holguin. Along the northeast coast is a folded zone that has been extensively intruded by serpentine. Both the Upper Cretaceous and the Middle Eocene are involved in the folding. Mention was made in the discussion of igneous rocks of the extensive intrusions in the northeast part of Oriente that form large structures surrounded by Tertiary marls and limestones. The prevailing structure of the metamorphics reported in the east end of Oriente is unknown.

HISTORY

The geological history of Cuba does not begin with any definite event or events. The oldest rocks of definitely known age are the Jurassic deposits of Pinar del Río Province. These are marine, and there is no evidence that any land existed at that time anywhere in the area now occupied by Cuba. Except for islands of varying size, there was nothing to suggest the present island until the Middle Miocene. To begin the geological history with events prior to this period is akin to ascribing to its political history events that occurred prior to 1492. The following is rather a history of that part of the Caribbean now occupied by the island of Cuba.

The known geological history of the area starts with the Jurassic. The accounts of events described as occurring in the pre-Cambrian, Paleozoic, and early Mesozoic may be dismissed as fantasies. They have been aptly, though conservatively, described as "contemplative geology . . . . giving a history essentially hypothetical."[57] It is true that the crystalline limestones and schists on the Isle of Pines and in the Trinidad Mountains appear to be old. There is, however, an entire lack of paleontological evidence from which their position in the column can be determined. They may with equal reason be ascribed to the Paleozoic or to the Tertiary.

There were several periods of folding. As far as known, only one, the first, was general throughout the island. The remaining orogenic events were more or less local in character, as is evident from the subsequent account.

JURASSIC

The distribution of the Oxfordian Jurassic indicates marine conditions in western Cuba. It is unknown elsewhere in the island. The thin, limy beds with a bituminous content were deposited in quiet waters at no great distance from land, but whether the land lay to the north or south can only be guessed.

In central Cuba and eastward in Camagüey Province the appearance of Upper Jurassic (Quemado formation) may be due to a general inundation of a large land mass or local embayments in such a mass. The localized occurrences near the north coast in central Cuba suggests the latter alternative. The clastic, calcareous sandstone of the Quemado was apparently deposited along the shore of a transgressive sea. Judging from later events, this land mass probably lay to the south.

In central Cuba the Upper Jurassic Quemado formation passes into the Lower Cretaceous Aptychus beds without a break. No evidence of orogeny between them has been noted.

The account of the late Jurassic orog-

[57] Hayes, Vaughan, and Spencer, p. 30 of ftn. 3 (1938).

eny described by Schuchert[58] was based on a failure to recognize the Pinar overthrust. The supposed unconformity between the Viñales (Aptychus beds) and the underlying younger Cayetano is the overthrust zone between the two.

CRETACEOUS

The local inundations during the Upper Jurassic were followed by complete submergence of at least the northern half of Cuba in the Lower Cretaceous (Aptychus beds). The coarse basal sand followed by the uniformly thinly bedded Aptychus-bearing beds reflect a transgressive sea that covered the five western provinces and probably also Oriente. The presence of Radiolaria and vegetal fragments and the uniformly fine-grained, thin-bedded marls indicate quiet waters at some distance from the shore but not beyond currents bearing debris from land.

A period of intense orogeny followed the deposition and consolidation of the Aptychus beds. This orogeny is unique in two respects: (1) it was the first definitely dated and (2) it was the most intense in the entire geological record of the island. From eastern Pinar del Río to eastern Camagüey badly sheared, contorted, and calcite-veined Aptychus beds are evidence of its intense, far-reaching effects. As far as is known, the activity in Cuba was confined to the northern half of the island. Here structural lines were laid out that were followed by all subsequent orogenies.

This folding event occurred within the North American realm and is of importance. In spite of its intensity and its locality, search for orogenic events on the North American continent comparable in time is vain. South America provides the only possible analogue in the New World. H. Stille states: "The South American Andes afford us on the whole the most striking example of subherzinian (intra-Upper Cretaceous) folding known to the present time."[59] While this pre-Laramide folding of the Aptychus beds cannot be dated except as between their deposition (Neocomian?) and the pre-Maestrichtian, this limit places it within the range of the Andean folding and suggests orogenic relationship between the Greater Antilles and South America. His statement that "weak subherzinian (intra–Upper Cretaceous) movements may likewise exist in Cuba"[60] may well have been prophetic of the discovery of this first great orogenic event in Cuba.[61]

TUFFS

During the deposition of the latest Aptychus beds there was initiated a long period of volcanic activity which continued during the rest of the Cretaceous and to the Middle Eocene. The center of this activity was in central Cuba, where 25,000 feet or more of tuffs, agglomerates, and flows accumulated. The activity extended to all the other provinces but with a lesser degree of intensity and was intermittent, both in space and in time. There are long and wide belts of deposits, long and narrow ones, and small isolated areas, and in many places they are entirely missing. Much or nearly all of Cuba was beneath the sea during this long period of vulcanism, as the numerous intercalated limestone lenses and Radiolaria and Foraminifera within the tuffs bear witness. Cuba, then, was in

[58] Pp. 33 and 517 of ftn. 24 (1935).

[59] "Die Entwicklung des Amerikanischen Kordilleren-systems in Zeit und Raum." Sitzungsber., *Preuss. Akad. Wiss., Phys.-Math. Kl.*, No. 15 (1936), p. 14.

[60] ". . . . schwache subherzynische Bewegungen mögen gleichfalls in Cuba vorliegen."

[61] P. 17 of ftn. 59.

effect a row of volcanic islands not unlike the inner row of volcanic islands in the Lesser Antilles. In time the activity was long ranged. In western Cuba it was Upper Cretaceous, in south-central Cuba from the Aptychus beds through the Upper Cretaceous, and in eastern Cuba it was Middle Eocene. In the latter case it was contemporaneous with similar activity in Haiti.

UPPER CRETACEOUS

The deposition of 34,500 feet of Cayetano consumed a long period of time. No explanation is offered for this formation's being limited to the province of Pinar del Río. Whether the remaining part of Cuba was above water and hence received no sediments or whether it was submerged and received sediments that were subsequently eroded cannot be answered. The high colors of the formation when weathered and the scarcity of fossils suggest estuarine or even freshwater deposition. Either of these postulates a much larger land mass in this part of the Caribbean than now exists. The limestone lenses with marine fauna may be due to local incursions of the sea. A noteworthy query is the origin of 34,500 feet of Cayetano sediments or the 30,000 cubic kilometers of this formation that has been eroded from Pinar del Río. Cuba could provide no bulk of this order. The sands predominate in the exposures on the north side of the Organos Mountains and shales on the south side, suggesting that transportation was from the north, an area now occupied by the Gulf of Mexico. This is in accord with the interpretation of the Lime gravels, but quite the opposite conclusion was reached in the case of the Big Boulder beds already described and also a part of the Habana formation.

The events occurring during the deposition of the Upper Cretaceous were outlined in part in the description of the Habana formation. The main series of events was, in general, as follows. It has been suggested that possibly most of Cuba was above water while the Cayetano was being laid down. At any rate, except for a few volcanic islands, Cuba was entirely submerged during the deposition of the Habana formation. This is shown by the presence of these marine beds both inland and near the coast in all the provinces of the island. In Pinar del Río, Habana, and Matanzas provinces the succession of Lime gravel, Cone sandstone, and Big Boulder beds indicates a near-by rising land which furnished coarse material. The presence of alveolinellid Foraminifera in Lime gravel pebbles is evidence of Cretaceous exposures in that terrain. The Cone sandstone, with its finer grain, may be interpreted as resulting from a lowering of the topography, possibly due to erosion. The location of the land mass is problematical. The finer-grained Lime gravels in the south anticline, as compared to the north, point to its location on the north. The advent of the Big Boulder bed with an almost complete change in lithology witnesses an equally marked change in the topography and perhaps in the location of the catering land mass. For the reason pointed out, namely, the larger boulders in the south anticline, this land appears to have lain to the south, in the opposite direction from the previous land that furnished the Lime gravels. The north limestone deeper-water phase (Jaronú formation) and the south conglomeratic phase of the Big Boulder bed (see Fig. 1) lend support to this suggestion.

The scattered volcanic activity during the deposition of the Big Boulder bed has already been noted. The tuffs with

marine fauna imply rather small volcanic islands.

It is a curious commentary that, in spite of the orogenic disturbances presumably necessary to produce the marked changes within the Maestrichtian sediments and of the vulcanism in that period, no evidence of any general movement during the Maestrichtian has been observed in Cuba itself.

Attention has been called to the Old World affinities of the Cuban Upper Cretaceous and Middle Tertiary faunas. The shallow-water, shore type of fauna makes the similarity the more striking. The explanation seems to lie either in a migratory route in shallow water along the shores of a Gondwana Land or Isthmian Link, as discussed by Willis[62] between North Africa and the Caribbean or in resorting to the Wegnerian theory of continental drift.

The granodiorite masses in Camagüey and western Oriente provinces, partly buried under unaltered Upper Cretaceous sediments, have been mentioned (p. 20). The evidence there leads to the conclusion that a large island mass was elevated sufficiently above the sea to allow erosion to expose the erstwhile deeply buried plutonic rocks and to reduce the island nearly to base level. The whole island was then lowered to receive the Habana formation sediments. The even larger mass of granodiorite in western Oriente Province appears genetically the same as that in central Cuba. The suggestion comes to mind that the various granodiorite masses are parts of a single mass more than 200 kilometers long extending through Camaguey and into Oriente Province. The existence of this Upper Cretaceous granodiorite island or islands has not heretofore been noted.

[62] P. 929 of ftn. 53 (1932).

ORIGIN OF SEDIMENTS

The south phase of the Habana formation and its equivalent are the only formations whose lithologic content evidences a foreign source. The shales, marls, chalks, and limestones in the various other formations are of material derived from near-by land or from the sea itself.

The source of a large portion of the sands and boulders in the few known Tertiary conglomerates can with considerable confidence be referred to antecedent formations, easily available through natural agencies of transportation. The siliceous content of the Cretaceous Cayetano formation is the logical parent of the sands and shales of the Paleocene Capdevila. The thinly bedded radiolarian limestone and black chert boulders in the Limestone breccia, and the Habana formation in the northern phase, with but little doubt were derived from the contiguous Aptychus beds. Search is in vain, however, for a parent of the highly diversified boulders of the Habana formation above listed (p. 13), nor could any older formation in Cuba have provided the bulk for the 34,500 feet of Cayetano. A source outside of Cuba must be sought. For reasons pointed out, the catering land mass must have lain to the south. The size of this Upper Cretaceous land was considerable. It bordered the entire south coast of Cuba except perhaps the eastern end. It extended an unknown distance to the south but at least as far as Jamaica, judging from the identity of the Upper Cretaceous shore fauna in Cuba and Jamaica. In Curaçao the rudist genera *Vaccinites* and *Durania*, which are common shore genera in Cuba, suggest land connections with northern South America. The presence of *Chiapasella pauciplicata* and other shore species in Cuba and Chiapas

indicate a connection with southern Mexico.

No rudist or molluscan fauna thus far reported from northern Mexico shows any relationship with the Upper Cretaceous fauna of Cuba. The same comment applies to Hispaniola and Puerto Rico. From the present data this land mass was therefore bounded in part on the north by Cuba and on the east by a line passing between Jamaica and Hispaniola and as far south at least as Jamaica and possibly to the north coast of South America. The lack of data on Upper Cretaceous history of Central America prevents any attempt to locate this line on the west except that it included Chiapas in southern Mexico.

PALEOCENE

At the close of the Cretaceous or the beginning of the Paleocene there was mild orogeny on the site of the future Organos Mountains in western Cuba. This is the first known folding in the western end of Cuba. It took the form of a low elevation on which the Cayetano formation was raised above sea-level and exposed to erosion. The very siliceous content of the Cayetano furnished the sands and shales of the Paleocene Capdevila that are exposed on both flanks and east of the mountains. At a distance from the mountains this formation lies upon the Habana formation with no indication of unconformity between them. Evidently the elevation was not sufficient to expose the Aptychus beds or their western equivalent, the Viñales formation, as no trace of limestone fragments has ever been reported from the Capdevila near the Organos Mountains. In passing, it should be emphasized that this is strong evidence supporting the contention that the Aptychus beds lie below the Cayetano. It was not yet exposed to erosion while the Capdevila was being deposited.

The Capdevila shales, sandstones, and rare conglomerates indicate near-shore conditions with no accentuated topography in the adjoining land mass. Near Capdevila, the type locality, ripple marks show actual strand conditions. A part of Cuba was at that time above water.

EOCENE

In Habana Province the shallow shore-deposited Capdevila is followed successively by brown and then white marls of the Universidad formation. The latter carry an abundant fauna of pelagic Foraminifera and Radiolaria bearing witness of a rapid submergence of considerable magnitude.

The later part of the Middle Eocene witnessed the second great period of orogeny. In Pinar del Río the presence of large boulders of both Upper and Lower Cretaceous rocks in early, rather steeply dipping, Upper Eocene, shows that the Organos Mountains had been elevated above the sea and were being subjected to rapid erosion. It is probable that the pivotal movement of western Cuba from an east-west to a southwest direction accompanied by the beginning of the Pinar overthrust occurred at this time.

This orogeny is the first of any great magnitude that western Cuba experienced. There is no evidence of the late Jurassic orogeny that produced the "ancestral Organos Mountains" mentioned by Schuchert.[63]

West of central Cuba the Habana-Matanzas and the Madruga anticlines were blocked out. At this time occurred the extensive overthrusting in northern Santa Clara when the Lower Cretaceous

[63] P. 496 of ftn. 24 (1935).

was thrust over the Upper Cretaceous and the Middle Eocene, the south phase of the Upper Cretaceous pushed northward in close proximity to the northern phase, and the Cordillera, in general, further elevated (Fig. 5). In Camagüey Province the 27,000 feet of Upper Cretaceous Jaronú limestone was folded. It seems probable that this orogenic activity extended to Oriente Province and continued eastward into Haiti and the Dominican Republic. In eastern Cuba there was extensive igneous activity, the record of which is preserved in the basalts of Sierra Maestra. The pillow structure of these basalts and the interbedded limestones are evidence that they were deposited under water.

In addition to the Organos Mountains, land of considerable elevation undoubtedly appeared throughout the areas of the structural features mentioned. The resulting group of elongated islands with east-west axes assumed a form roughly outlining Cuba as now known. This great period of orogeny corresponds in part to the Laramide revolution on the North American continent.

The widespread distribution of the deep-water Upper Eocene indicates a general subsidence during which probably the greater part of Cuba was again flooded. In Habana City the Upper Eocene is a pure-white marl which is for the most part massive, carries much fossil salt, and is characterized by a distinctly deep, open-water foraminiferal fauna. Land debris is entirely absent. The foraminiferal assemblage of the marls, acording to D. K. Palmer,[64] indicates a depth of water of at least 600 feet. This is about at the edge of or somewhat beyond the continental shelf. In Matanzas, Santa Clara, and Camagüey provinces similar deposits indicate similar conditions.

The Trinidad Mountain overthrust is the only tectonic event noted in Cuba in the Upper Eocene. This is dated on rather good evidence. On the flanks of the overthrust area the Cretaceous is a limestone in which no schist boulders have been found. Above the Cretaceous the Middle Eocene and the lowest Upper Eocene are fine-grained, white chalk. At the top of the Upper Eocene a conglomerate appears with boulders of Trinidad schists. Evidently the schists were not exposed before this time. Though the Trinidad overthrust and the overthrust zone in the northern part of the island both resulted from the same forces of compression, the evidence indicates that the two movements were not contemporaneous but that the one in the north was the earlier.

Widely distributed clastic sediments in the Lower Oligocene record a renewed elevation. These occur in all the provinces except Matanzas (see p. 17), where the Lower Oligocene is a deep-water marl. The greater part of Cuba was elevated, and low islands were exposed which provided the small amount of land-derived material that enters into the composition of these sediments. The wide distribution of the Lower Oligocene marine deposits indicates that the islands were not of great extent.

During the Middle Oligocene, Cuba experienced a mild deformation during which the various formations flanking the structures were elevated. Erosion beveled these exposed areas and provided the diversified surface on which the Güines limestone was deposited. Submergence of that surface took place in the transitional Oligo-Miocene and Lower Miocene and was one of the most

[64] "The Occurrence of Fossil Radiolaria in Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vol. VIII (1934), p. 79.

extensive that Cuba has experienced. In the west, islands probably persisted on the site of the present Organos Mountains. All of Habana and Matanzas provinces were open ocean. A few islands marked the Cordillera in Santa Clara, and shallow water covered most of the remaining parts of the province. The sea crossed western Camagüey and covered the southern part of the province, extending eastward into the Cauto Valley of Oriente Province. The deposits laid down during this widespread marine incursion are the Güines limestone. This is the most extensive and most unconformable formation in Cuba. Normally it rests on the Cojimar formation (Upper Oligocene), but it is transgressive on various stages of the Oligocene, on the Eocene, and even on the Upper Cretaceous. During this period there was nothing that suggested the Cuba of the present.

Late in the Lower Miocene there occurred another mild orogeny. Quantitatively the movements were small, but, as shallow water covered the deposits involved, the effects were striking. Cuba emerged and for the first time assumed approximately its present outline. The old structures were rejuvenated, and further folding occurred along the Habana-Matanzas and Madruga anticlines. The latter presented an aspect very different from the present. Instead of the broad valleys that now mark these features the Güines limestone covered them in the form of a low swell. Post-Miocene erosion has removed the Güines from the higher elevations and has exposed the softer Eocene and Cretaceous marls, shales, and sandstones, leaving the line of cliffs retreating down the flanks of the two anticlines as stated in the discussion of the third physiographic unit and the second structural unit. In Santa Clara Province the Cordillera was further folded. In Camagüey and Oriente provinces the history is not known in detail, but post-Miocene elevation and minor folding have been recognized.

Deposits subsequent to the Lower Miocene are rare and confined to the coast or inlets of the coast. Examples are the Middle Miocene La Cruz marls in Santiago de Cuba and Manzanillo in Oriente Province. In Matanzas Province the Middle Miocene is exposed on the Canímar River, in a narrow belt extending westward from Matanzas City, and in the gorge of Yumurí River. In the last two localities the inclination of the Middle Miocene beds is greater than can be attributed to initial dip. As they are on the flank of the Habana-Matanzas anticline, it is evident that post-Middle Miocene folding has taken place in this structure.

During the Pleistocene and Recent, vertical movements of considerable magnitude are recorded in the terraces and in sand-choked river channels. Hayes, Vaughan, and Spencer[65] record terraces in widely separated parts of the island. In each locality there are from three to five. The highest are, in Habana, 200 feet; in Matanzas, 300 feet; in Gibara on the north coast of Oriente Province, 150–80 feet; in Manzanillo, 200 feet; and in Santiago de Cuba, 280 feet; while Point Maisí at the extreme eastern end of Cuba is estimated to be 600 feet in height. These wave-cut terraces indicate wide marine incursions.

The drowned valleys that form the harbors of Cuba and the sand-choked river channels are evidence of former elevations of the land or lowering of the sea. In the channel to Habana Harbor that cuts through hard limestone there is 100 feet of sand; in the Almendares

[65] P. 18 of ftn. 3 (1938).

River channel on the west edge of Habana there is 69 feet, and in the valley of San Juan River in Santiago de Cuba, Hayes, Vaughan, and Spencer[66] noted rounded boulders 70 feet below sea-level. Whether there was actual elevation or a lowering of the sea, possibly as the result of the withdrawal of water required in the accumulation of the Pleistocene ice caps, cannot be answered.

Wave-cut terraces above 35 feet elevation have not been observed in Santa Clara or Camagüey provinces. However, there is striking evidence of folding accompanied by elevation in the Cordillera in eastern Santa Clara. The Jatibonico del Norte River crosses a wide limestone ridge in the Cordillera through a natural tunnel. Above the tunnel and passing over the ridge 200 feet above the entrance to the tunnel is the former clear-cut channel with boulders brought from the igneous terrain in the upper reaches of the basin. Salvador and Sarah Massip[67] have also observed this feature. Along the north coast of Camagüey Province a syncline is forming between the mainland and the outer row of islands. Such phenomena as drowned drainage courses, a warped, oxidized surface that is submerged, and drowned vegetation furnish evidence both of the structure and of its recent advent.

Taber[68] considers the faulting of the Bartlett Deep and the rising of the Sierra Maestra as Pleistocene events.

The clear evidence of recent movements from the eastern tip of Cuba westward to Habana prompts the suggestion that the Pinar overthrust in the western end may have been active at least during the Pleistocene or Recent. It is recognized that earlier orogeny had left local high hills or mountains during the Lower and Upper Eocene. The boulder content of conglomerates of that age bear witness of this. Similar features continued with or without interruption into the Oligocene and probably into the Miocene. The thrusting, however, at least in its final stages, occurred at a later time. The deep and very steep drainage courses in the soft Cayetano shales are the result of recent elevation. These shales border the overthrust sheet on the north and participated in the movement of the overthrust. On the north side of the overthrust sulphide ores occur on the surface of the Cayetano shales, indicating erosion of such rapidity that oxidized products could not accumulate. In the tropics this implies very recent elevation. The limestone mogotes, though subject to acid solutions from the dense growth of vegetation, retain a young topography (Fig. 2). A striking example of recently formed topography is the scar, earlier described (Fig. 3 and p. 21), that marks the south front of the overthrust. Though the terrain is the soft Cayetano shales, the face of the scar is still steep and scarcely gullied, and the top or crest has no more than started to retreat. The relative recency of the uplift of these mountains is well shown in the north coastal plain. The portion of the plain lying north of the mountains has a youthful topography with sharp ridges and active streams. On the other hand, the adjacent portion to the east and beyond the end of the mountains has a mature topography with low, rounded hills and sluggish water courses.

[66] *Ibid.*, p. 34.

[67] *Introducción a la geografía de Cuba* (Habana, 1942), p. 95.

[68] P. 597 of ftn. 2 (1934).

BIOLOGICAL EFFECTS OF GEOLOGY

The vicarious events in the geological history of Cuba have had a vital effect on the biological content of the island.

It is only through such favorable events as the appearance of land that terrestrial or marine shore life was even possible. To a satisfactory understanding of the living fauna and flora as well as the fossil, the general geological background is of material assistance.

Attention has been called to the fact that, with the possible exception of portions of the Cayetano formation, the sediments of Cuba are entirely marine. The absence of terrestrial deposits effectually answers the often-repeated question of why no land-vertebrate fauna is ever found in the Cretaceous or Tertiary of Cuba. The only vertebrate remains are a few Pleistocene forms found in cave deposits near Ciego Montero and Mayajigua in Santa Clara Province.

The striking feature of the Cuban mammalian fauna is its scantiness. A list of the living and fossil mammals of Cuba has been compiled by Dr. G. Aguayo of the University of Habana. This comprises 59 species, and his analysis shows that 3 insectivores, 2 carnivores, 5 edentates, and 9 rodents, or 32 per cent, make up the entire list of strictly land mammals. The remaining 40 species, or 68 per cent, are bats, cetaceans, and a sirenian. To the first group, a passage across water is a fortuitous event and accomplished but rarely. Sufficient time has not elapsed for this group to land more than a few species. The flying and swimming mammals, however, quickly populated the island and adjacent waters, and the species soon reached a maximum.

Three factors contributed to the paucity of the strictly land-mammal fauna. First, the shortness of the time available for its development. As pointed out earlier, Cuba as a large island such as it is today did not exist until after the Middle or Upper Miocene. The small islands that marked its location did not afford either space or variety of habitats for an abundant and diversified mammalian fauna.

The second factor is one of both space and time. The source of the Cuban mammalian fauna appears to be South America. Two migration routes have been suggested. One, over former land connections through Central America and by way of Honduras, Jamaica, and Hispaniola to Cuba. The other, via the Lesser Antilles, Puerto Rico, and Hispaniola, and, finally, Cuba. In either case, only the tapering ends of the migrations reached Cuba in the limited time available. This was a factor in the low census of Cuban mammals.

The third factor, equally important and possibly the most important, is the Pleistocene or recent submergence of Cuba. The terraces along the north coast, and also those on the south coast of Oriente Province, evidence a Pleistocene or later repetition of the Miocene marine inundation. They indicate that the submergence was of the order of 300 feet or more. This submergence, coupled with the fact that many areas were at that time at a relatively much lower elevation than at present (see pp. 32–33), killed off the greater part of the terrestrial life. Except for the descendants of those few types that found refuge on the scattered Pleistocene islands and possessed the hardihood to meet the fierce competition in those crowded quarters, the present fauna as well as the flora of Cuba are post-Pleistocene arrivals.

SOME REVISIONS OF THE LATE CENOZOIC STRATIGRAPHY OF THE SOUTHERN OREGON COAST[1]

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ABSTRACT

The Elk River beds of the Cape Blanco region, as currently referred to, include terrace deposits of late to post-Pleistocene age and beds of Middle Pliocene age which unconformably underlie them. The writer proposes to restrict the name "Elk River beds" to the terrace deposits in accordance with Diller's original definition and further proposes the name "Port Orford formation" for the beds of Middle Pliocene age, as yet bearing no formational name. The name "Coquille formation" is proposed for estuarine deposits which unconformably underlie the Elk River beds (restricted) just north of the Coquille River mouth. The Coquille formation is tentatively correlated with a part of the Taholah formation of Washington. Two stages of marked elevation above sea-level were recognized, the latter followed by submergence of the coast line to its present position. The formation of the late to post-Pleistocene terrace was accompanied and followed by gentle warping.

INTRODUCTION

Recent studies by the writer along the coast of southern Oregon in 1943 and 1944, while mapping with the State Department of Geology and Mineral Industries, have indicated a need for revision and clarification of the Pleistocene and some Pliocene stratigraphic units exposed in the sea cliffs. A similar study of the Pleistocene stratigraphy of the Olympic coast of Washington was undertaken by the writer in 1938[2] and led to the following conclusions. Beds which had been generally assigned to the Pleistocene are separated by an unconformity; unconsolidated terrace deposits overlie older estuarine sediments. Truncation of the estuarine sediments by the sea formed a wave-cut platform upon which the terrace deposits later were laid. The estuarine sediments are confined to channels cut in the Tertiary rock during a former stage of emergence. The recent studies show that similar stratigraphic units are present along the southern Oregon coast.

[1] Published with permission of the director of the Oregon Department of Geology and Mineral Industries.

[2] "Late Cenozoic Diastrophism along the Olympic Coast, Washington" (unpublished Master's thesis, Washington State College, 1939).

DESCRIPTION OF THE TERRACE

Remnants of a prominent marine terrace are well displayed at Cape Arago and Cape Blanco along the southern Oregon coast. The terrace approximates sea-level between Heceta Head and Coos Bay, but south of Coos Bay it rises to as much as 225 feet at Cape Blanco. The wave-cut platform upon which the terrace sands and gravels rest truncates folded Tertiary and pre-Tertiary sediments and igneous rock as well as older Pleistocene estuarine deposits. In some places alluvial-fan material is spread over the terrace top where it borders highlands. The terrace is poorly developed on igneous or pre-Tertiary rock, and it is therefore missing along much of the coast south of Port Orford and is barely visible at Heceta Head. The terrace is several miles wide where the Tertiary sediments border the present shore line, although much of the former surface has been recently cut away by the sea.

Streams are entrenched where they cross the terrace, but the intervening surface presents the initial slope marred only by bars, dunes, and small areas of fanglomerate. Good sections of terrace

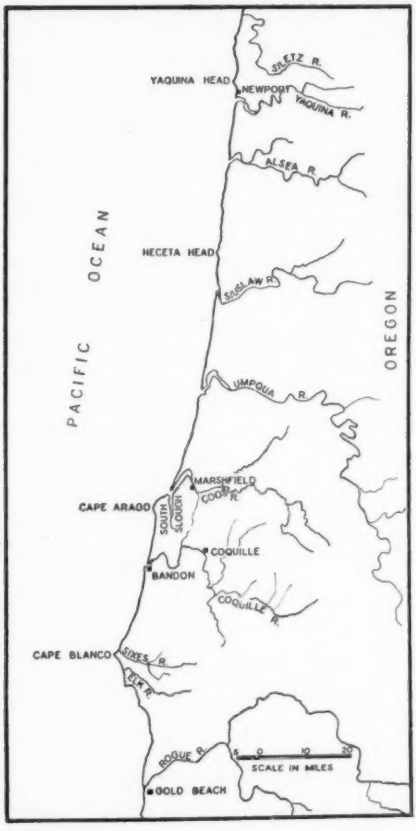

FIG. 1.—Index map of the southwestern Oregon coast.

deposits are exposed along the beach, where they rest upon the wave-cut platform. The unconformity surface, although undulating, is remarkably smooth except near the former shore line, whose location is indicated by wave-rounded and pholad-bored rock. The plane of unconformity is below sea-level between Heceta Head and Coos Bay, but it is exposed in the higher portions of the terrace from South Slough to Port Orford. Some of the range in elevation of the terrace, as well as the platform in the exposed beach section, might be explained by the initial slope of the old sea-bottom and the relative distance from the old shore line. Although some initial slope of the terrace is acknowledged, warping of the coast line is believed to account for most of the range in terrace and platform elevation in the beach section. Along the old strand line, where initial slope cannot be considered a factor, differential elevations afford more definite proof of warping.

Although there is a series of higher marine terraces along the Oregon coast, reaching altitudes as high as 1,500 feet, specific reference to a terrace will be confined to the one described, and the others will be referred to collectively.

PREVIOUS WORK

Few writers have dealt with the late Cenozoic stratigraphy and history of the Oregon coast. J. S. Diller[3] described and defined several stratigraphic units during his extensive geologic investigations. W. D. Smith[4] has described many of the coastal features in some detail. J. T. Pardee[5] illustrated many of the coastal sections in his report on beach placers.

[3] "Topographic Development of the Klamath Mountains," *U.S. Geol. Surv. Bull. 196* (1902), pp. 30–31; "Coos Bay, Oregon," *U.S. Geol. Surv. Folio 73* (1901); "Port Orford, Oregon," *U.S. Geol. Surv. Folio 89* (1903).

[4] "Physiography of the Oregon Coast," *Pan-Amer. Geol.*, Vol. LIX (1933), pp. 33–44, 97–114, 190–206, 241–58; Smith and R. E. Fuller, "Oregon Shorelines: A Report of Progress" (Abst.), *Bull. Geol. Soc. Amer.*, Vol. XLI (1930), p. 153; Vol. XLIII (1932), p. 243.

[5] "Beach Placers of the Oregon Coast," *U.S. Geol. Surv. Circ. 8* (1934), pp. 1–41.

More recent studies of the black sands by W. H. Twenhofel[6] and A. B. Griggs[7] have helped explain the origin of the marine terraces. The invertebrate paleontology of Cape Blanco has been recently studied by O. L. Bandy.[8]

STRATIGRAPHY

PORT ORFORD FORMATION

The name "Port Orford formation" is proposed by the writer for Middle Pliocene beds lying unconformably between the Empire and the overlying terrace deposits exposed south of Cape Blanco within the Port Orford quadrangle (Fig. 2). This formation has been included with the terrace deposits under the name "Elk River beds" (or formation),[9] but in reality it is a separate stratigraphic unit.

The basal bed of the Port Orford formation is a buff sand overlain by conglomerate and separated from it by a local unconformity (Fig. 3). Above the conglomerate is a rusty sand which grades upward into a blue-gray argillaceous sand which bears fossiliferous concretions. The top of this member has been truncated by the sea, and the overlying loose gray sand is the basal bed of the late to post-Pleistocene terrace deposits which Diller[10] named the "Elk River beds." He failed to differentiate between the Empire sediments and those referred to here as Port Orford and included both in the Cape Blanco beds.

R. Arnold and H. Hannibal[11] recognized the unconformity between the Empire and the sediments of the Port Orford formation which they believed to be Upper Pliocene, but they included the younger Pliocene beds with the overlying Pleistocene terrace deposits and referred to them as the "Elk River formation."

More detailed work by Bruce Martin[12] confirmed the probable Pliocene age of some of the sediments in Arnold and Hannibal's Elk River formation, but he recognized the Pleistocene age of the upper portion. He concluded that the series was not separated by a stratigraphic break even though the faunas and lithology were sufficiently distinct to allow the series to be separated into two horizons. He evidently failed to recognize the wave-cut surface which truncated the Port Orford sediments and upon which the Elk River terrace deposits rest with apparent conformity but separated by a considerable lapse of time. Martin reported abundant fossils in both the Pliocene and the Pleistocene beds near the mouth of the Elk River. He noted the prominent shell bed at the base of the thin terrace deposits just south of the cape and fossils in the uppermost part of the section near the mouth of the Elk River. The faunas contained a few species not common to both, but the difference in fauna, he concluded, might be caused by the difference in position with regard to the strand line. The time necessary to lay down the terrace

[6] "Origin of the Black Sands of the Coast of Southwest Oregon," *Oregon State Dept. Geol. & Min. Ind. Bull. 24* (1943), pp. 1–25.

[7] "Chromite Sands of the Coast of Southwestern Oregon" (manuscript in preparation, United States Geological Survey).

[8] "Invertebrate Paleontology of Cape Blanco" (unpublished Master's thesis, Oregon State College, 1941).

[9] M. G. Wilmarth, "Lexicon of Geologic Names of the United States," *U.S. Geol. Surv. Bull. 896* (1938), pp. 673–74.

[10] P. 31 of ftn. 3 (1902).

[11] "The Marine Tertiary Stratigraphy of the North Coast of America," *Proc. Amer. Phil. Soc.*, Vol. LII (1913), p. 604.

[12] "The Pliocene of Middle and Northern California," *Calif. Univ. Dept. Geol. Sci. Bull.*, Vol. IX (1916), pp. 219–20.

FIG. 2.—Beach section just north of the mouth of Elk River. (1) Elk River beds. (2) Plane of the wave-cut platform. (3) The Port Orford formation. (4) Woody sediments which are tentatively correlated with the Coquille formation (Fig. 6).

FIG. 3.—Local unconformity in the Port Orford formation

deposits would probably be so short that Martin's explanation for the slight difference in fauna seems acceptable.

W. D. Smith and E. L. Packard[13] mention "two distinct horizons above the Empire (at Cape Blanco), the lower one being presumably the Cape Blanco beds of Diller." However, Diller used the term "Cape Blanco beds" to include both the Empire and the younger Pliocene (Port Orford formation).

cluded all the original Elk River beds (Table 1).

The unconformity is slightly angular at the northern end of the exposed Port Orford sediments, which dip more steeply than the overlying Elk River beds; and the blue-gray argillaceous sand of the Port Orford nearly pinches out, allowing the conglomerate of the Port Orford to be confused with slumped gravels of the terrace deposits.

TABLE 1

HISTORICAL SUMMARY OF THE DIVISIONS PROPOSED FOR THE CAPE BLANCO SECTION

Diller (1902)	Arnold and Hannibal (1913)	Martin (1916)	Bandy (1941)	Baldwin (1945)
Elk River Beds			Terrace Deposits	Elk River Beds
unconformity	Elk River Formation	Elk River Beds	*unconformity*	*unconformity*
			Elk River Formation	Port Orford Formation
Cape Blanco Beds	*unconformity*	*unconformity*	*unconformity*	*unconformity*
	Empire Formation	Empire Formation	Empire Formation	Empire Formation

Bandy[14] concluded that the sediments here referred to the Port Orford formation were Middle Pliocene instead of Upper Pliocene, as proposed by Arnold and Hannibal and later by Martin. He excluded those terrace deposits which contained the shell bed near the cape and restricted the name "Elk River formation" to the sediments of Middle Pliocene age. This completed the evolution of the name from its original application by Diller to its use for the Middle Pliocene sediments by Bandy, who ex-

[13] "Salient Features of the Geology of Oregon," *Jour. Geol.*, Vol. XXVII (1919), p. 100.

[14] P. 25 of ftn. 8.

COQUILLE FORMATION

The name "Coquille formation" is proposed for the section of gently deformed sediments exposed in the beach section between Whiskey Run and Cut Creek just north of the Coquille River mouth (Table 2) (cf. Figs. 4 and 5).

The measured section was the thickest continuous section, but it does not represent all that is exposed because of intervening areas of slumped Elk River beds. Where the measurement was taken, the dip was as high as 25°, thus exposing 93 feet, but other isolated exposures of the formation which were generally horizontal could not be placed with cer-

tainty in relation to the measured section. The total exposed thickness is probably in excess of 200 feet, and a greater original thickness is implied because the upper portion has been removed by the sea and the base is beneath the sea. At the mouth of Whiskey Run the Coquille formation unconformably overlies the Umpqua formation.

The sediments appear to be estuarine in origin, and, because of their location, they appear to fill a former valley of the Coquille River before its mouth was shifted southward by the present sandspit (Fig. 4).

TABLE 2

MEASURED SECTION OF THE COQUILLE FORMATION

	Feet
Conglomerate	24
Bed containing stumps and peat	2–3
Coarse sand with some grit and logs	18
Sand and woody material above a local unconformity	10
Cross-bedded sand with woody material and an occasional pebble lens	30
Thin-bedded sandy clay	9
	93+

Several feet of clay and peat of similar stratigraphic position are exposed at low tide in the point which separates the south end of South Slough. This is the only place where sediments were observed between the Empire and the Elk River beds.

Sand and clay containing abundant pieces of wood are exposed in the cliff near the natatorium at Newport, Oregon, beneath the wave-cut platform. These sediments are similar in lithology and stratigraphic position to the Coquille formation and are correlated with it.

Sediments which contain abundant woody material are exposed unconformably above the Port Orford formation in the small valley in the beach section midway between Cape Blanco and the mouth of Elk River (Figs. 6 and 2). The stream of this valley is a tributary to the Sixes River drainage and was apparently beheaded by the advancing sea. The bottom of the old valley is only a few feet below sea-level, so that it is not likely that the Sixes River ever drained through to the sea by this route, in light of previous downcutting exhibited in the Coquille and other river valleys. The sediments are obviously not a part of either the Port Orford or the Elk River beds, and from their stratigraphic posi-

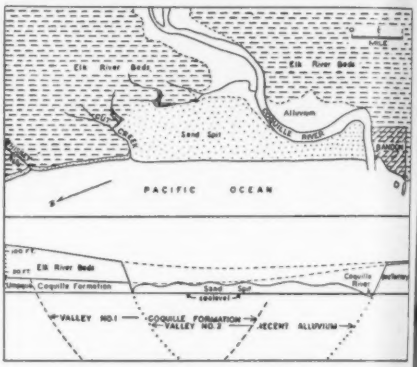

FIG. 4.—Plan view and cross-section of the mouth of the Coquille River.

tion and similar environment of deposition, as suggested by abundant woody material, they may be the equivalent of the Coquille formation.

Similar sediments occupying an analogous stratigraphic position along the Washington coast have been studied by the writer. These sediments, which appear to fill former valleys, are well displayed near the mouths of some of the streams, an example of which is displayed just south of the Hoh River mouth. These sediments have been included by S. L. Glover[15] in his Taholah

[15] "Pleistocene Deformation in the Olympic Coastal Region, Washington," *Northwest Sci.*, Vol. XIV (1940), p. 69.

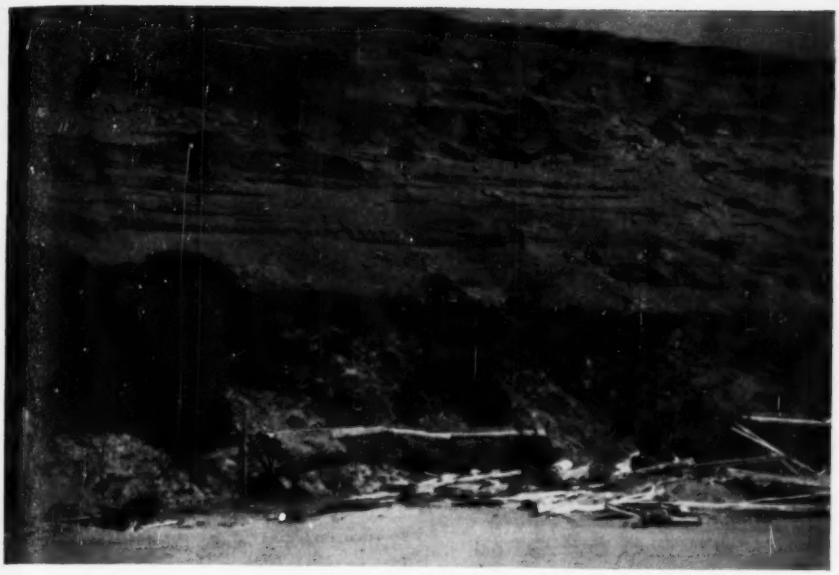

FIG. 5.—Elk River beds lying unconformably above the Coquille formation just south of the mouth of Whiskey Run. The wave-cut platform coincides with vegetation that grows beneath the line of water seepage.

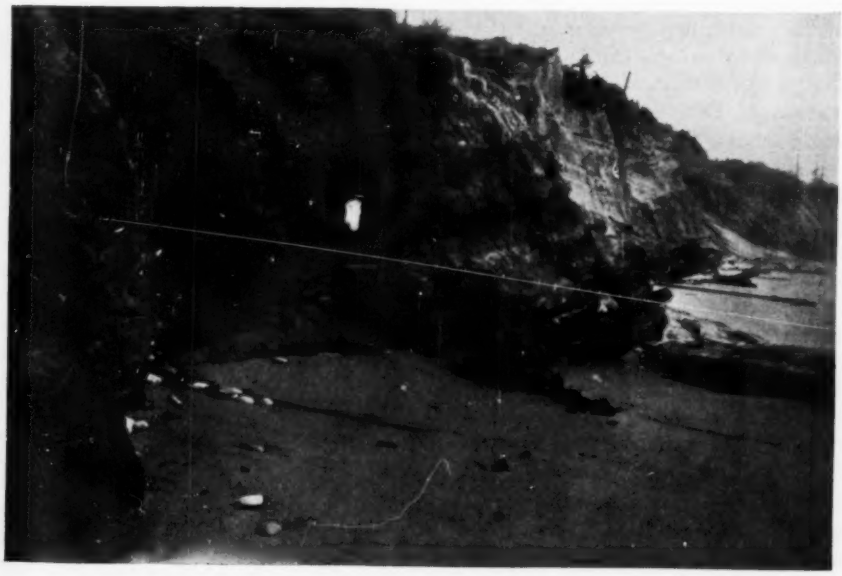

FIG. 6.—Sediments containing intercalated peat and logs which were deposited in a former tributary valley of the Sixes River.

formation along with a much thicker section of sediments in the Taholah-Moclips area, which he described as follows:

> One outstanding example is in the Taholah-Moclips vicinity where a sedimentation phase of the Taholah formation occurs that is quite distinct from the usual type. In this particular area the sands, gravels, and occasional clays were deposited in a subsiding basin, presumably an estuary, and so accumulated to a thickness far greater than is known elsewhere on the coast. Detailed sections of as much as 475 feet have been measured, and the persistent structural attitude of scattered exposures indicates that the total thickness of the formation is in excess of 1,500 feet.

There appears to be no faunal evidence to indicate the age of this section of sediments. However, the Taholah formation seems to include sediments deposited under different conditions: those laid down in erosional valleys and those deposited in a subsiding basin. It would be coincidental if the two were of the same age. Until further work clarifies the limits of the Taholah formation, a correlation of the Coquille formation of Oregon can be tentatively made only with that portion of the Taholah which appears to occupy former stream valleys.

Sediments of the Coquille formation and those believed to be their equivalent are classified as valley fills because they have steep erosional contacts and lie between Tertiary or pre-Tertiary masses beneath the wave-cut platform; they contain coarse-grained to fine-grained beds with local unconformities, cross-bedding, and many pieces of wood; their areal extent is believed to be too small to be explained by subsidence; and they are without known exception near a stream mouth.

If the interpretation that these isolated deposits represent deposition in valleys formed during a prior stage of emergence is correct, sediments of this stage might be expected to be found at the mouths of all the larger streams along this part of the coast. There are at least two factors which prevent this from being true. Erosion during a later stage of emergence has removed the Coquille sediments from the valleys except at the mouth of the Coquille River and in a few other places where a shift of the river's course has preserved them. Then, too, the wave-cut platform is beneath sea-level or buried by extensive sand dunes for many miles in down-warped parts of the coast, so that sediments of this stage, if present, cannot be seen.

The age of the Coquille formation is believed to be very late Pleistocene, but it will be further discussed in the summary of the geologic history.

ELK RIVER BEDS

The Elk River beds, as defined by Diller[16] and used by the writer, consist of the terrace sands and gravels which rest upon the wave-cut platform. Although he did not elaborate as to the presence of or type of unconformity, Diller's diagram of the Cape Blanco region shows this to be true. The sediments range in thickness from 10 feet near the cape to 90 feet just south of the mouth of Elk River. The basal loose gray sand is eroded more rapidly than the underlying Port Orford sediments, thus accentuating the break. Above the basal sands, rusty gravels predominate. Sediments forming this same terrace farther north along the coast of Oregon are more sandy, and north of Coos Bay they are generally re-worked as dunes. The name "Elk River beds" should apply to all the terrace deposits forming this terrace along the Oregon coast.

[16] Pp. 30–31 of ftn. 3 (1902).

Fossils, which Martin[17] concluded were Recent forms, are abundant at the base of the Elk River beds just south of Cape Blanco, and farther south they are intercalated with the thicker terrace deposits. These were studied later by Bandy,[18] who likewise concluded that they were Recent forms and deposited under cold-water conditions.

The upraised marine terraces of the Ventura region of California have been studied by Putnam,[19] who concluded that the higher terraces resulted from diastrophism rather than from fluctuations of sea-level. Faunas on even some of the higher terraces were identified by Grant,[20] who concluded that they suggested a post-Pleistocene age. Bailey[21] indicated that a probable late Pleistocene age for the entire series of marine terraces was to be inferred from their truncation of more steeply dipping beds of Upper Pleistocene age. The relationship between the California and Oregon marine terraces has been pointed out by Gale,[22] who stated:

> The whole western border of the continent seems to have been uplifted gradually as a unit, or the sea level may have subsided eustatically, or both processes may have worked simultaneously. . . . . The youngest series of marine terraces exposed at various places along the coast from San Diego to Oregon seems to be remarkably uniform in general features, though the individual terraces vary in number and height because of minor local warping.

[17] P. 247 of ftn. 12 (1916).

[18] P. 46 of ftn. 8.

[19] "Geomorphology of the Ventura Region, California, *Bull. Geol. Soc. Amer.*, Vol. LIII (1942), p. 752.

[20] *Ibid.*, p. 700.

[21] "Late Pleistocene Coast Range Orogenesis in Southern California," *Bull. Geol. Soc. Amer.*, Vol. LIV (1943), p. 1554.

[22] U. S. Grant, IV, and H. R. Gale, "Pliocene and Pleistocene Mollusca of California," *Mem. San Diego Soc. Nat. Hist.*, Vol. I (1931), p. 64.

Although individual terraces of the Oregon coast may not be correlated with those of the California series, the Elk River beds would appear to be one of the younger—very late to post-Pleistocene in age.

EVIDENCE OF COASTAL WARPING

Warping of some of the younger marine terraces along the California coast has been recognized by Davis,[23] Putnam,[24] and others. Smith[25] has suggested warping along the Oregon coast, and Pardee[26] referred to differential uplift. The youngest of the uplifted marine terraces along the Washington coast has been studied by the writer[27] and the warping plotted.

The datum plane used in measurements was the terrace level at the old strand line, which may be identified by pholad borings and a well-defined notch at the base of the slope back of the terrace, as is so well demonstrated at Yaquina Head. Measurements are based upon hand leveling, triangulation, and United States Geological Survey topographic data. Two datum planes were measured—the top of the terrace and the top of the wave-cut platform—but the evidence for warping is based primarily upon the top of the terrace. The plotted sections in Figure 7, with the exception of that at Cape Blanco, were taken at or near the old strand line and are believed to be correct to within a few feet.

Although the plotted elevations are not evenly spaced along the shore line,

[23] "Glacial Epochs of the Santa Monica Mountains, California," *Bull. Geol. Soc. Amer.*, Vol. XLIV (1933), pp. 1068–69.

[24] P. 752 of ftn. 19 (1942).

[25] P. 101 of ftn. 4 (1933).

[26] P. 31 of ftn. 5 (1934).

[27] Pp. 18–20 of ftn. 2 (1939).

they do indicate warping of the coast line after deposition of the Elk River beds. Thickening and thinning of the terrace deposits suggest warping of the wave-cut platform during terrace deposition, as is shown at Cape Blanco, the highest point on the terrace. The wave-cut platform is 200 feet above sea-level at the cape, but it disappears beneath the sea 3 miles south at the mouth of the Elk River (Fig. 2). The top of the terrace is 225 feet in elevation at the cape and drops to 50 feet at Port Orford, 7 miles to the south. The dip of the underlying

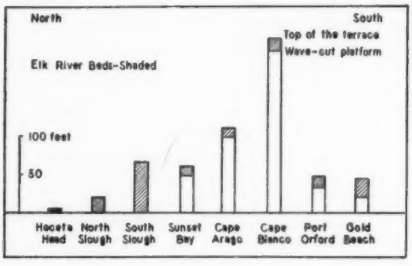

FIG. 7.—Plotted elevations of the top of the terrace and the wave-cut platform.

Port Orford formation is greatest where it overlaps the Empire, probably caused by compaction of the sediments in the basin of deposition; but along the greater part of the section it is generally parallel to that of the warped terrace deposits.

The streams to the north of and including the Coquille River drain relatively low-lying areas of soft Tertiary rock. They have broad flood plains, unfilled bays, and the tidal currents affect the river as much as 35 miles upstream—facts which have led to the conclusion that they have been submerged to a greater extent than rivers to the south of the Coquille River which have a steeper gradient and a narrower valley cut in pre-Tertiary rock. This supposition is not supported by relative elevation of the terrace. An examination of the Rogue River valley indicates that it, too, has a flood plain, but the original valley was narrower, because it was cut in more resistant rock, and the heavily laden stream has aggraded its valley so that the tidal currents do not extend far upstream.

RECENT FAULTING

Small displacements in the terrace deposits are fairly common. One of the larger of the faults, with a 10-foot slip, parallels the steep bedding plane of the Eocene coal bed at Mussel Reef near the Cape Arago lighthouse. This fault, like others in the vicinity, is a small reverse bedding-plane fault.

SUMMARY OF PLIOCENE AND PLEISTOCENE HISTORY

Deposition of the Empire formation in the Coos Bay area started during the latter part of early Pliocene time and continued throughout most of the Middle Pliocene, according to Weaver.[28] Deformation of the Empire beds in the Cape Blanco region preceded the deposition of the Middle Pliocene Port Orford formation, resulting in an angular discordance of 15°–20° and a pronounced erosional break between the two formations.

Deformation of the Port Orford prior to terrace formation seems to have been largely confined to compaction of the sediments, which has caused the beds to dip more steeply away from the Empire near the contact.

From later Pliocene to the Middle Pleistocene was a time of erosion which accompanied and followed the uplift of the Coast Range. Recent work along the California coast, already cited, indicates a late to post-Pleistocene age for even

[28] "Correlation of the Marine Cenozoic Formations of Western North America" (chart), *Bull. Geol. Soc. Amer.*, Vol. LV (1944), opp. p. 596.

some of the higher terraces. Terraces which are found even higher than 1,500 feet point to regional uplift because they seem too high to be accounted for entirely by eustatic changes in sea-level.

Davis[29] has suggested a correlation between terrace formation and stages of glaciation and deglaciation. Although the higher terraces are probably too high to be explained by eustatic changes, two stages of stream cutting beneath present sea-level and the lower terraces may reflect eustatic changes accompanying the last two periods of glaciation during later stages of regional uplift.

If the older of the resultant valleys, the one in which the Coquille formation was deposited, was formed before the higher terraces, the valley would have been filled during the ensuing submergence with resultant changes in stream courses, and evidence of this has not been recognized in the valleys. It does not seem likely that regional trends would be reversed to allow uplift, submergence to at least 1,500 feet, and then uplift again, as demonstrated by the steplike marine terraces. It seems more probable that the older of the two valleys was formed by relative changes in sea-level, probably eustatic in nature, in the latter part of the present regional uplift. Further work in the Puget Sound area will probably help to correlate the history of the Coquille River as outlined with the latest glacial and interglacial stages. It seems probable that the Coquille formation antedates most of the higher terraces and is therefore late to very late Pleistocene in age.

The following stratigraphic column places the late Cenozoic stratigraphic units in their relative order. It must be emphasized that dating of the younger formations is tentative because of the early stage of study of Pleistocene-Recent history along the Pacific Coast (Table 3).

The history of the Coquille River shows the two stages of emergence above present sea-level, and a diagrammatic cross section indicates their probable history (Fig. 4). It is popularly believed that the Coquille River flowed into Coos Bay by way of the "isthmus" near Coaledo which now separates drainage to the Coos and Coquille rivers. Twenhofel[30] indicated that this was the case and that, "when the submergence of the coast began [the submergence prior to the formation of the 1,500 foot terrace and the rest of the terrace series], ... the present valley of the Coquille River into the Bandon area did not then exist."

TABLE 3

Very late Pleistocene to post-Pleistocene	Elk River beds
Late Pleistocene	Coquille formation
Middle Pliocene	Port Orford formation
Upper lower Pliocene and Middle Pliocene	Empire formation

Evidence of two former valleys at the mouth of the Coquille indicates that the river followed approximately its present course even before headward erosion of Beaver Slough, a tributary of the Coquille, and Isthmus Slough, a tributary of the Coos River, formed the pass between the two drainages. The former stages of emergence, shown at the mouth of the Coquille River, would have formed the "isthmus" during stages of downcutting, and therefore it would be unnecessary to postulate deep valley formation prior to regional uplift.

The Coquille formation, deposited in valley No. 1 (see Fig. 4), was some time later truncated by the sea and then covered by a veneer of terrace deposits,

[29] P. 1045 of ftn. 23 (1933).

[30] P. 20 of ftn. 6 (1943).

the Elk River beds. Deposition of the Elk River beds was followed by relative uplift, at which time the present terrace was much higher than now, and valley No. 2 was formed. Later drowning of valley No. 2 has returned the terrace to its present level and filled this valley and its re-entrants as much as 35 miles upstream. Above tidewater, the present valley of the Coquille becomes V-shaped and the gradient increases. Valleys corresponding to No. 2 are filled south of the Coquille River, but to the north, bays and lakes occupy the unfilled portions of these valleys because the streams drain less rugged areas and carry smaller loads.

Diller[31] cited drilling operations which penetrated 200 feet of alluvium without reaching its base, and a projection of the stream and tributary profiles suggests an even greater filling.

Although the present trend of relative movement of sea-level was not determined, the submergence which drowned valleys corresponding to valley No. 2 must be fairly recent because of the unfilled nature of the lakes and bays.

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[31] "Coos Bay, Oregon," *U.S. Geol. Surv. Folio 73* (1901), p. 3.

EXAMPLES OF THE INTERPRETATION OF FOLDING

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ABSTRACT

Two examples of folded strata are discussed, in which bedding-plane slip is revealed by the displacements of transverse quartz veins from bed to bed. Detailed examination of a specimen containing argillaceous and arenaceous lamellae affords evidence for an interpretation of the internal readjustments by mass flowage, bedding-plane slip, and slip along planes of fracture cleavage, that went on during folding. The fracture cleavage, although parallel to the axial planes of the folds, is believed to have formed obliquely to the *AB* plane of the strain ellipsoid.

INTRODUCTION

The genetic interpretation of minor structures in folded rocks that exhibit cleavage but are otherwise little metamorphosed is not easy, since decisive petrofabric data such as may be obtained from coarsely crystalline tectonites are difficult to obtain. Hans Cloos[1] has, however, demonstrated that under favorable circumstances the nature of certain internal adjustments that have taken place in the folding of such rocks can be determined. In the example he describes, optical evidence of congruous bedding-slip[2] was obtained from slickensides and from the displacements of pretectonic transverse quartz veins from bed to bed.

GOLDEN STAIRS MINE

A similar example, regarded by the present author as comparable with that described by Cloos, occurs at the Golden Stairs Mine, near Melbourne, Victoria, where the section surveyed by J. P. L. Kenny[3] shows several congruous displacements of the auriferous quartz veins from bed to bed on the limb of an anticlinal fold. The rocks are interbedded Silurian sandstones and mudstones, folded into an open anticline with dips, at the Mine, of 20° on the limbs. In the section at Morrisey's Reef a vertical quartz reef crossing the strata shows a succession of offsets along the bedding planes, each of about 2 feet, the movement in the upper bed of any two being toward the crest of the fold. The rocks are seen in the field to be massive, without well-defined stratification planes within the individual beds, which would account for the restriction of bedding-slip to the major bedding planes. The stratal gliding units were the individual beds. In closely folded, laminated Silurian sandstones in the Melbourne area, on the other hand, it has been shown by the author[4] that gliding in folding took place between the thin laminae themselves, as well as on major bedding planes. The thickness of stratal gliding units is particularly important in regard to the position of the neutral surface in neutral surface folding. Clearly, where laminae are the units in gliding, each lamina has its own neutral surface, and the amount of compression and elongation, respectively, below and above this surface is much less in a thin

[1] "Der Gang eine Falte," *Fortschr. der Geol. etc.*, Bd. XI, Hft. 33, pp. 73–88.

[2] In this paper the term "congruous" is applied to such movements of strata as are believed to have resulted from the normal processes of internal readjustment accompanying the formation of individual folds.

[3] "Golden Stairs Mine, Greensborough," *Rec. Geol. Surv. Vict.*, Vol. V, Part II (1936), pp. 222–23.

[4] E. S. Hills, "The Silurian Rocks of the Studley Park District," *Proc. Roy. Soc. Vict.*, Vol. LIII, Part I (1941), pp. 167–91.

lamina than it is in a thick, massive bed. This relationship in turn affects the form assumed by different rocks under similar tectonic conditions and goes far toward accounting for the frequent development of close and acute folds in thin-bedded rocks, as compared with the broader and more open folds of massive strata. The fact that, as will be shown below, laminae only a few millimeters thick may act as stratal gliding units is, therefore, worthy of note.

The implication at the Golden Stairs Mine that the quartz veins were emplaced before the folding was completed is important, since it has been generally assumed that the auriferous quartz reefs in the central Victorian gold fields were introduced after the folding of the Ordovician and Silurian rocks of the region. It would appear that there was some overlap of the metallogenetic epoch and the diastrophic period.

FOLDING IN A LAMINATED ROCK

A large specimen from the gorge of the Mitta Mitta River at Mitta Mitta, Victoria, reveals particularly well, by the displacements of quartz veinlets, the relative movements of stratal gliding units in folding. The rock consists of laminated sandstone and dark, gray-black slate (Fig. 1). The stratification planes in the sandstones are spangled with a phyllitic development of small mica flakes, but otherwise recrystallization is not notable, apart from the normal reconstitution of the slate.

Bedding-slip.—The rock is traversed by several minute quartz veinlets, the offsetting of which in adjacent laminae reveals systematic bedding-slip displacements which are clearly connected with differential gliding or shearing among the laminae during folding (see Figs. 1 and 2). Most of the displacements are congruous with relation to the geometrical form of the folds, but the two veinlets (*I*) show incongruous movement with relation to the adjacent anticline. They may have been injected after the formation of the anticline and have been displaced by bedding-slip during the formation of the small subsidiary syncline on the flank of which they occur. If so, they are of slightly later origin than the group above described. The similarity in trend of the various veinlets suggests that they have all similar histories, yet the widest shows no evidence of displacement by bedding-slip, although it is cracked through parallel to the stratification planes. This indicates that the sandstone laminae were not sufficiently strong to transmit a stress capable of shearing the broad veinlet; the cracks are regarded as shear joints, developed along planes of incipient shearing after some change in the tectonic setting of the rock. The inability of the sandstone laminae to shear this veinlet through may be accounted for, since the veinlet is thicker than any lamina present, and, being composed of a mosaic of crystalline quartz, it would have a greater strength than the granular sandstone, which also contains a little argillaceous material. It is therefore suggested that, even if the folding had progressed further, this relatively thick quartz veinlet would not have been sheared as were the thinner ones, along the planes of lamination of the rock.

Flow in argillaceous material.—The veinlets may still be recognized where they pass into the central dark argillaceous layer (now slate), and it may be seen that there has been no post-vein shearing along the topmost sandy bedding plane (Fig. 1, *B*), since, although mass movement has taken place, the continuity of the veinlets is maintained across this bedding plane. Furthermore, there

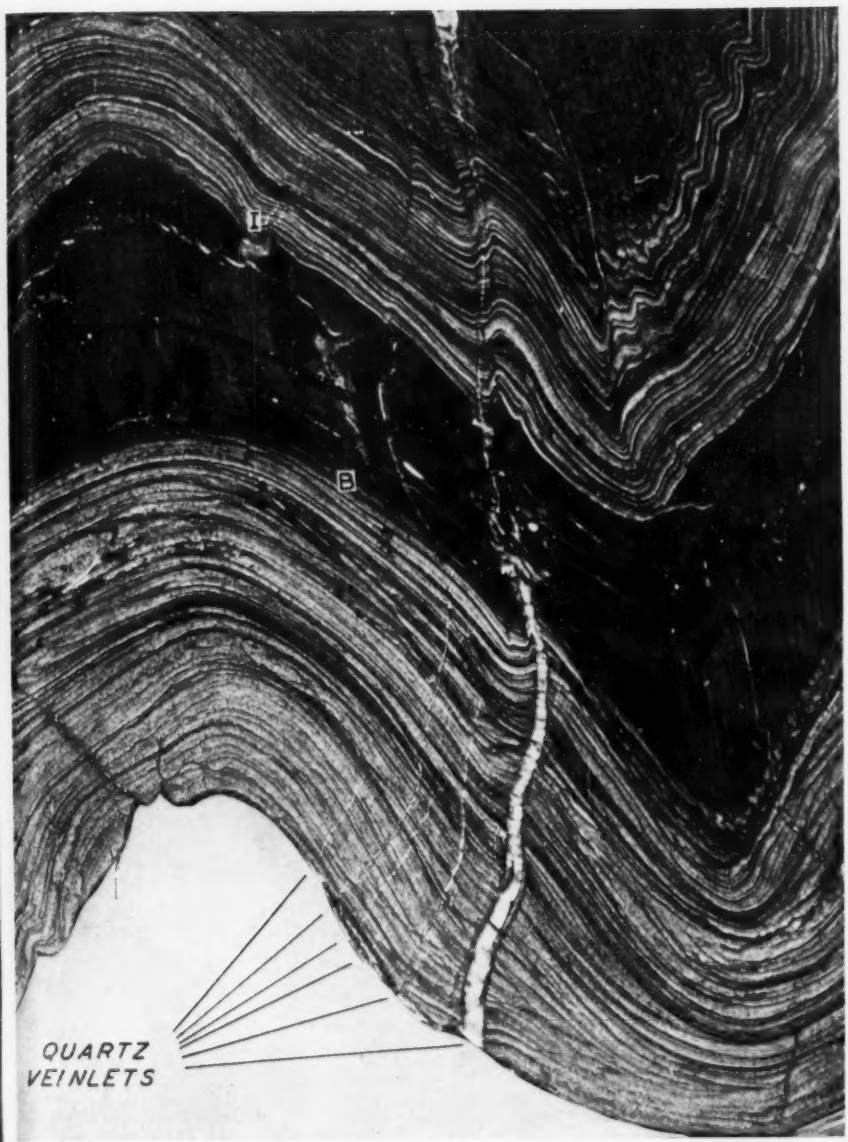

FIG. 1.—Laminated sandstones and slates, Mitta Mitta River, Mitta Mitta, Victoria. Slightly enlarged.

is no evidence of bedding-slip having occurred along any stratification plane within the slate, but the veinlets show strong general curvature indicative of mass flowage of the enclosing argillaceous material.

Under the microscope, it is seen that the quartz has been deformed, first, as a result of differential flowage of the surrounding rock-mass in the general direction of the bedding and, second, by shearing along planes of later development, lying at an angle to the bedding and constituting a type of fracture or slip-strain cleavage (Fig. 4). The microfoliation, as shown by the parallel development of micaceous minerals, is parallel to the bedding in this rock and is quite unrelated to the planes of fracture cleavage.

The amount of flowage since the formation of the veinlets may be inferred from the bending shown by them, and it will be seen that there was a progressively greater amount from about the middle of the right-hand limb of the anticline, toward the axis of the fold. This flowage is explicable according to the usual interpretation of similar folding, in which incompetent rocks undergo mass movements from the limbs toward the axes of folds.

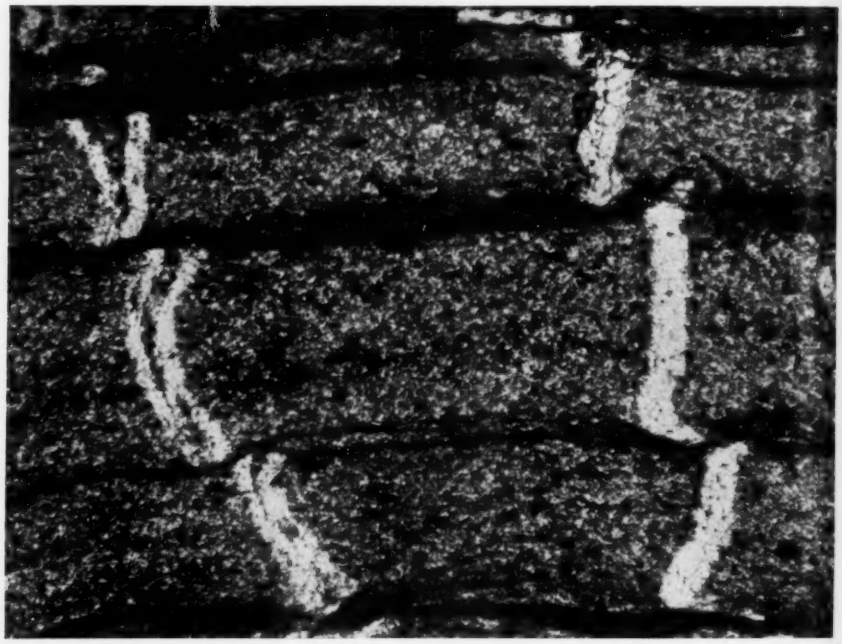

FIG. 2.—Quartz veinlets in laminated sandstone, showing displacements by bedding-slip during folding. ×25.

Slip-folding.—As may readily be seen in Figures 1 and 5, much information about the displacements within the slate can also be obtained from a study of the very thin laminae of slightly different color that are revealed when a smooth surface is flooded with water or oil. By this means, it is possible to reveal struc-

FIG. 3.—Portion of lower right-hand corner of Fig. 1 enlarged to show concentration of slip-planes in the right-hand unit of the syncline (compare Fig. 7.) ×2.

tures that are practically invisible in the untreated specimen.

Evidence for slip-folding is shown, the laminae exhibiting a succession of displacements along closely spaced, statistically parallel shearing planes, whereby a general foldlike form is produced.

FIG. 4.—Quartz veinlet in slate, showing effects of shattering by flowage parallel to the bedding (horizontal); planes of false (strain-slip) cleavage are of later development. ×25.

We have, therefore, evidence for three different types of internal readjustments in this rock, presumably all related to folding. The bedding-slip phenomena in the laminated sandstones indicate that these folded mainly by flexing, accompanied by only minor internal readjustments of grain structure connected with the slight plastic deformation of the laminae above and below their neutral surfaces. Mass flowage of the incompetent argillaceous material occurred during the earlier stages of the formation of the folds, but finally this material yielded by slipping along closely spaced shearing planes, producing slip-folds, while the purer arenaceous material continued to yield by flexing. The relationships where arenaceous and argillaceous laminae alternate and are subequal in importance in the makeup of the rock are, however, not so clear cut. We find, for example, that thin arenaceous laminae embedded in the argillaceous material are sheared through along the cleavage planes, while other arenaceous laminae show various intermediate stages between such clear-cut shearing, shearing with marked "drag," and small-scale flexural folding. Certain generalizations concerning these phenomena are discussed below.

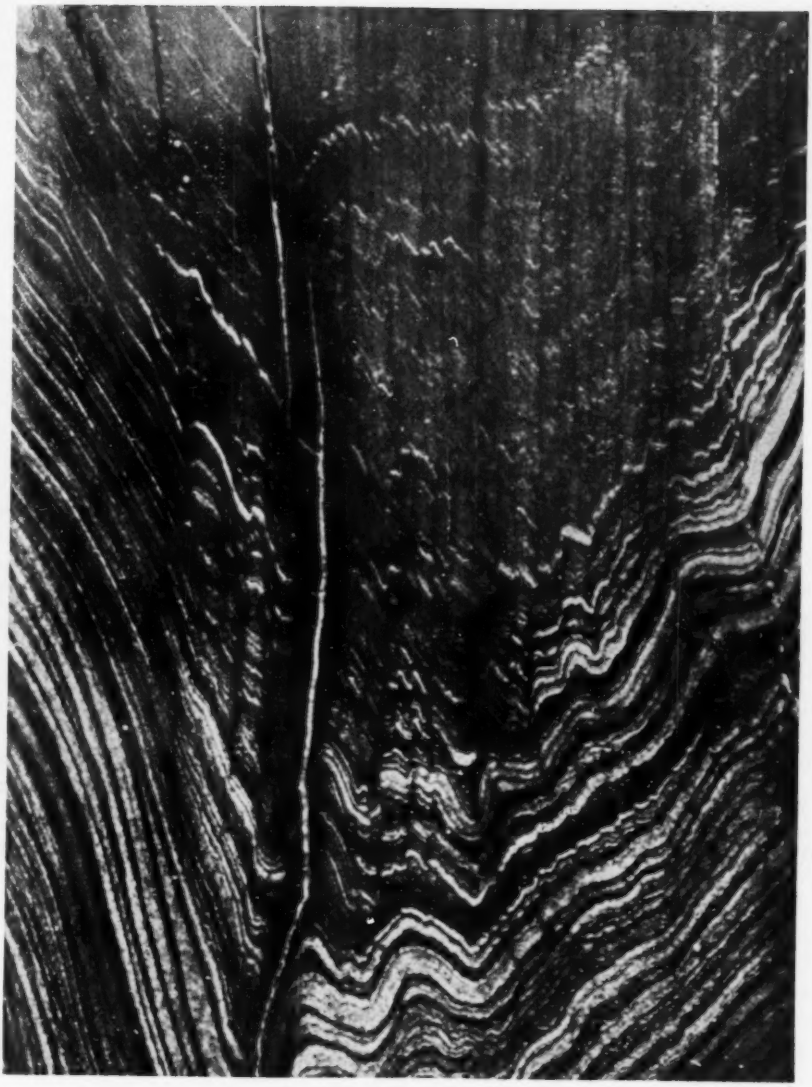

FIG. 5.—Portion of top right-hand corner of Fig. 1 enlarged to show slip-folding in laminated slate. ×4.

Spacing of slip planes.—Study of the arenaceous laminae embedded in the slate and sheared through along the cleavage planes leads to the conclusion (Item 1) that, the thicker the sandy lamina involved, the wider the spacing of the planes of slip (fracture cleavage) within it (see Fig. 6).

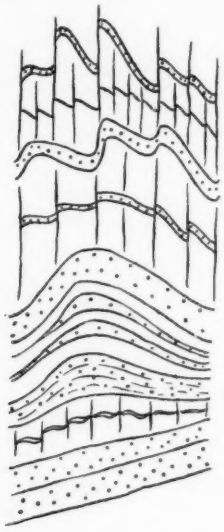

FIG. 6.—Sketch to show relationship of shear planes and folds to lithology in laminated slate and sandstone.

This relationship indicates a connection between the spacing of slip planes and the physical properties of the sheared rock. For a given amount of deformation, if few shearing planes are developed, the movement along each must be greater than if a larger number of planes is active. If, when a few shearing planes have formed, it is easier for slip to continue along these than for new planes to originate, the spacing will remain wide and the movement on each plane will be great. In a sandstone the internal friction is presumably great, so that it should be easier to continue movement along a shearing plane already formed, and on which the friction may have been reduced by attrition of angular grains, than to originate a new plane in such granular rock. It is probable that the thicker sandy laminae in the rock in question contain less argillaceous material than the slightly darker and finer-grained thin sandy laminae, so that the internal friction in the thicker laminae would be greater. In view of the relationships expressed in Item 1 above, it therefore appears that the spacing of shearing planes in the various laminae present is directly related to the internal friction. This relationship, however, may not apply to other examples of plastically deformed rocks. It will be affected by work hardening, especially in the plastic flow of crystalline rocks, and, for a given rock under various tectonic conditions, by the amount of plastic deformation that is required.

Transition from slip to flexural folding.—On this topic the generalization (Item 2) may be made that with an approximately constant amount of slip along any one shearing plane traversing several arenaceous laminae (as shown in Fig. 6):

1. Thin laminae are sharply separated on either side of the plane;
2. Thicker laminae show marked "drag" which tends to provide a shear link between the displaced parts;
3. Thicker laminae still are "folded," with a marked thinning of the sheared limbs of the folds;
4. In the dominantly arenaceous parts the shears die away.

These relationships appear to be connected, first, with the ability of any particular layer or group of laminae to yield by bedding-slip. We note (*a*) that bedding-slip has occurred between the laminae in dominantly arenaceous material

and (*b*) that bedding-slip did not occur in dominantly argillaceous material.

Most probably such slip was inhibited within the latter because the adherence of the rock across the stratification planes was stronger than the shearing-stress component along them. The argillaceous material was, therefore, statistically isotropic in its reaction to stress, and the shearing planes developed in it must, therefore, have a definite geometrical relationship to the stress-axes. In the dominantly arenaceous material, on the other hand, the resistance to shearing is less in the stratification planes than in the rock itself. Such material is anisotropic in its relation to stress; shearing tends to be restricted to the bedding planes (bedding-plane slip) and has no constant geometrical relationship to the stress-axes.

Intermediate stages between slip and flexual folding (Item 2*b*, *c*) occur where the arenaceous and argillaceous laminae are subequal in the composition of the rock.

Consider first the condition with sandy laminae that yield along the shearing planes by flexing, with stretching of the sheared limb of the flexure. In such shear flexures an individual shearing plane in the argillaceous material, on passing into the sandstone, becomes a shear zone with lateral drag effects. Second, with thicker sandstones, the necessary dip shift along a shearing plane or group of planes is achieved by a hinge rotation, resulting in a flexural fold. The formation of such folds involves bedding-slip, which commences to operate when the resistance to shearing in a thick sandy lamina becomes greater than the adhesion of the argillaceous to the arenaceous material. This relationship thus sets a limit to the spacing of shearing planes in the sandy laminae, above discussed, and determines whether slip-folding or flexural folding will operate in any part of the rock mass. Furthermore, where the arenaceous and argillaceous laminae occur in about equal amount, the folding is of the flexural-slip type, both processes being of approximately equal significance. This term is also appl cable to the specimen considered as a whole.

MECHANICS OF FOLDING

In attempting to unravel the rather complex structural history of the specimen, it is necessary to work backward from the final stage, t at of slip-folding. It may be observed, in considering the attitude of the stratification planes in the slip-folded argillaceous material, that the very thin laminae in the core of the syncline are parallel with the bedding planes in the left-hand limb of this fold (see Fig. 1 [top right-hand corner] and Fig. 5).

This relationship implies that these laminae, and also the laminated sandstone beds over and underlying them in the right-hand limb of the fold near the axis, were, before the formation of the slip fold, parallel to the beds in the left-hand limb. As the laminae are traced farther to the right, however, they gradually change their attitude until they are parallel to the beds in the rest of the right-hand limb. A similar condition is to be seen in the left-hand limb of the anticlinal fold.

These features are interpreted as follows: At a certain stage in deformation, before slip-folding was initiated, the rock as a whole developed similar flexural folds, involving flowage and bedding-slip. The end of this stage was reached with the anticlinal and synclinal axes in the positions A^1 and S^1 shown in Figure 7. The quartz veinlets were injected before

the completion of this stage of the folding.

Further deformation, resulting in a shifting of the anticlinal and synclinal axes closer together, was achieved by continued flexural folding of the dominantly arenaceous material with slip-folding in the argillaceous material, as shown in the figure. The important point is that, during this stage, the left-hand limb of the syncline remained fixed while the right-hand limb was rotated, and the fold axes closed in. With a slip-fold in

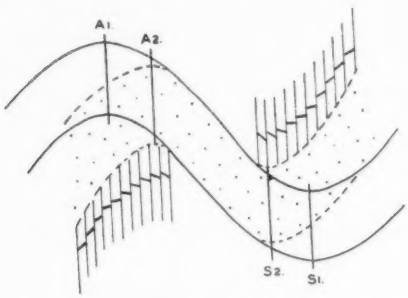

FIG. 7.—Suggested stages in folding. A^1, S^1, anticlinal and synclinal axes before slip-folding; A^2, S^2 positions of axes after slip-folding with a stationary middle limb.

which both limbs rotate about a fixed axis, the throw on the shearing planes is right-hand-up in one limb and left-hand-up in the other.[5] In the example here described, on the other hand, the displacements are right-hand-up along all shearing planes in the vicinity of the fold axes.

CONCLUSION

In their different reactions to stress, including shearing, shear-flexing, and flexural folding, the various laminae in the rock under discussion exhibit different degrees of competency, affording a clear analogue on a minute scale with the structures of larger folds. Obviously, none of the laminae can be termed "competent" in the sense used by Willis,[6] that is, competent to "carry up the weight of overlying strata"; but C. M. Nevin[7] has pointed out that "no bed or formation is sufficiently competent to support itself, let alone lift a considerable burden of overlying rock, under conditions common to folding." The fundamental principle of competency, especially of relative competency, may perhaps best be considered in terms of those properties that determine the geometry of strata in folding. For the rock under discussion, the properties involved would appear to be (*a*) the internal resistance to shear across the bedding; (*b*) ability to yield by slip along bedding planes; and (*c*) ability to yield by mass flowage.

Strata that can yield readily by flowage exert little influence on the general form of folds, except as they transmit hydrostatic pressure, afford lubrication, and, as it were, "fill the spaces" between more competent strata. They accommodate themselves freely to the geometrical forms assumed by the other rocks present and are at the lowest grade of competency.

In strata that yield by slip-folding we have to deal with a more regulated type of plastic flow, in which the displacements, especially along the shearing-planes, bear a definite geometrical relationship to the stress-axes. In the rock under discussion slip-folding and flexural folding are related, but, in the sense of influencing the geometry of the fold, the argillaceous material, as is normally the case, was clearly less competent than the arenaceous at the stage of

[5] B. Sander, *Gefungekunde der Gesteine* (Vienna: Julius Springer, 1930), Fig. 145, p. 269.

[6] *Geologic Structures* (New York: McGraw-Hill Book Co., 1934), p. 79.

[7] *Principles of Structural Geology* (New York: John Wiley & Sons, 1942), p. 50.

slip-folding. As we have seen, mass flowage preceded slip-folding in the argillaceous material, so that presumably some change in the constitution and physical properties of this material took place at a certain stage in the deformation. This stage probably marks the formation of reconstitution minerals in the parts that are now slate. Although there may be slates that do not exbihit slip-folding, as soon as an argillaceous rock does yield in this way, it becomes a slate, and the planes of slip constitute a variety of false cleavage. In the present example the cleavage is an axial-plane cleavage, but, as the above analysis shows, it comprises only one set of shearing planes, which were not predetermined by any inhomogeneity in the rock and, therefore, must be regarded as lying obliquely to the AB plane of the strain ellipsoid.

This in turn indicates the necessity for some reservation in accepting the widely held view that "the axial planes of folds are essentially perpendicular to the least strain axis."[8]

[8] M. P. Billings, *Structural Geology* (New York: Prentice-Hall, Inc., 1942), p. 216.

AN OCCURRENCE OF "CAVE PEARLS" IN A MINE IN IDAHO[1]

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ABSTRACT

Pisolites up to 13 mm. in diameter occur in depressions in a veneer of calcium carbonate which mantles rubble in an abandoned mine. They were formed by precipitation from mine water, and the high polish that characterizes some specimens is due to agitation caused by dripping water. The period of formation is 35–42 years.

INTRODUCTION

Pisolites, formed by the accretion of concentric layers of calcium carbonate around a nucleus, have been described by Frank L. Hess[2] from specimens collected by Lee in the Carlsbad Caverns, by W. D. Keller[3] from a cave in Missouri, and by Norbert Casteret[4] from a cave in France. Edvard Erdman[5] has discussed their formation in a mine in Sweden, and W. H. Twenhofel[6] has called attention to the growth of somewhat analogous oölites in a water-heating system. The pisolites treated here differ in some respects from those described in these earlier papers, shed light on the origin of the high polish that characterizes the type of pisolites known as "cave pearls," and are of special interest because the period required for their formation is known.

The pisolites were found by Mackin in the course of an examination of an abandoned prospect adit in the Iron Mountain district in southwestern Idaho—the lower adit on the south side of the West Fork of Crawford Gulch (S.W. ¼, sec. 12, T. 14 N., R. 6 W.). The petrographic studies, photomicrographs, and pictures were made by Coombs.

According to Messrs. John Siegwein and Frank Mortimer, of Weiser, Idaho, the adit in question was opened in 1901. It is possible that it may have been cleaned out in the interval between 1901 and 1908, when patent was issued on the mining claim. So far as is known, no work has been done on the property since that time. In other words, the period of development of the pisolites is 35–42 years (1901 or 1908 to 1943).

OCCURRENCE

The country rock in the Crawford Gulch prospect is a coarse-textured marble which is locally mineralized at

[1] Published with permission of the director, Geological Survey, U.S. Department of the Interior.

[2] "Oölites or Cave Pearls in the Carlsbad Caverns," *No. 2813 of Proc. U.S. Nat. Mus.*, Vol. LXXVI, art. 16 (1930), pp. 1–5. For an early mention of the Carlsbad oölites, and an illuminating discussion of both organic and inorganic coated stones, see Heinrich Schade, "Zur Entstehung der Harnsteine und ähnlicher konzentrisch geschichteter Steine organischen und anorganischen Ursprungs," *Zeitschr. f. Chem. u. Ind. d. Kolloid.*, Vol. IV (1909), pp. 175–80, 261–66. This important article, apparently little known to geologists, was called to the writer's attention by W. H. Bradley. A digest was prepared by Gordon L. Bell.

[3] "Cave Pearls in a Cave near Columbia, Missouri," *Jour. Sed. Pet.*, Vol. VII (1937), pp. 263–65.

[4] *Ten Years under the Earth* (New York: Greystone Press, 1939), pp. 204–6.

[5] "Stalagmit och pisolitartade bildningar i Hoganas stenokolsgrufa, Shone," *Geol. fören i Stockholm förhandl.*, Vol. XXIV (1902), pp. 501–7.

[6] "Oölites of Artificial Origin," *Jour. Geol.*, Vol. XXXVI (1928), pp. 564–68.

and near the margins of a quartz-diorite intrusive body; the adit was driven in search for a sulphide vein. The portal is partly caved; and, though the air is

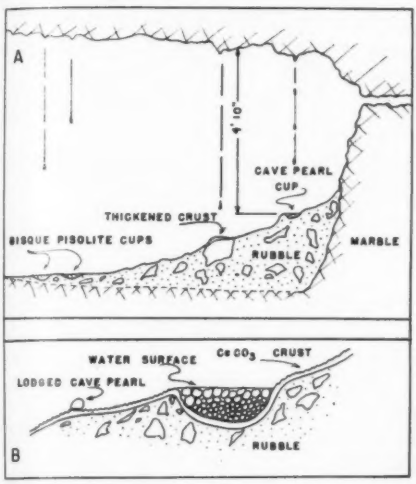


FIG. 1.—*A*, diagrammatic section of adit, to show occurrence of "cave pearls." *B*, detail of "cave-pearl" cup.

fresh, there is no free circulation. The walls and floor of the adit in a segment 80–120 feet from the portal are more or less completely covered by a rough calcium-carbonate crust ranging from a thin film to several centimeters in thickness; the surface of the crust is kept wet by seepage from the walls and dripping from the roof. The pisolites occur in shallow, cuplike depressions in rubble on the floor and at the base of the walls (see Fig. 1).

Two of the cups, 5–7 cm. in diameter and 3–5 cm. in depth, contain pisolites whose brilliant polish amply justifies the term "cave pearls." In both cups ten to fifteen round to subround, relatively large "pearls" (10–13 mm. in diameter) form a distinct surface layer flush with the rim (see Fig. 2, *A*, right). The underlying pellets are smaller (2–4 mm.) and have corners and edges more highly polished than the flat or re-entrant faces (see Fig. 2, *A*, center). The interior walls of the cups are smoothly undulating surfaces exhibiting the same high polish as the contained pellets, contrasting markedly in this respect with the surrounding rough-surfaced crust.

Both of the "cave-pearl" cups are on a slope above the general level of the floor of the adit (Fig. 1, *A*); about ten of the larger-sized pellets, evidently derived from the cups, are lodged on the descending slope and on adjoining parts of the floor. All are cemented in place, some still retaining a brilliant polish on the upper parts, some having the polish

A

B

FIG. 2.—*A*, the small "cave pearls" in the center are from 2 to 4 mm. in diameter; the larger specimens on the right vary from 10 to 13 mm. in diameter. The bisque-surfaced pisolite on the left shows polished interior growth layers. *B*, rough and bisque-surfaced pisolites. The specimen in the center is 25 mm. in diameter.

frosted over in greater or less degree, and some being so completely crusted by calcium carbonate as to appear as rough projections above the adjacent surface.

Of nine other nests of pisolites observed in the adit, four contain subrounded pellets showing some polish on nodes and edges but with a general surface texture similar to that of unglazed porcelain or bisque china. The remaining cups are shallow and less regular in form and are set apart from the others by the fact that some of the contained pisolites are cemented to the floor and walls; most of the free pisolites are rough surfaced, some are smooth, but none show areas of polished surface. Finally, various irregular shallow depressions on the floor of the adit contain rough, subangular pisolites, the majority cemented in place.

The pisolites may be grouped, then, into three main types: (1) the highly polished "cave pearls" (Fig. 2, *A*, center and right); (2) bisque-surfaced pisolites, including those locally polished on nodes and edges (Fig. 2, *B*, center and right); and (3) rough-surfaced pisolites (Fig. 2, *B*, left). There are, of course, gradations between these types. Some bisque-surfaced pisolites show inner-growth rings which are highly polished (Fig. 2, *A*, left).

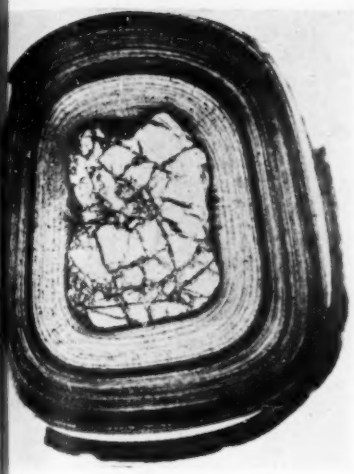
PETROGRAPHIC DESCRIPTION

All of the pisolites, whether they be smooth or rough, have a nucleus of some type; but these vary greatly in size and shape. Some of the nuclei are covered by a very thin coating of calcium carbonate; in others the coatings are extremely thick and represent by far the greater volume of the "pearl." The smooth and more rounded types usually have a thicker coating than the rough subangular or noded types (see Fig. 3).

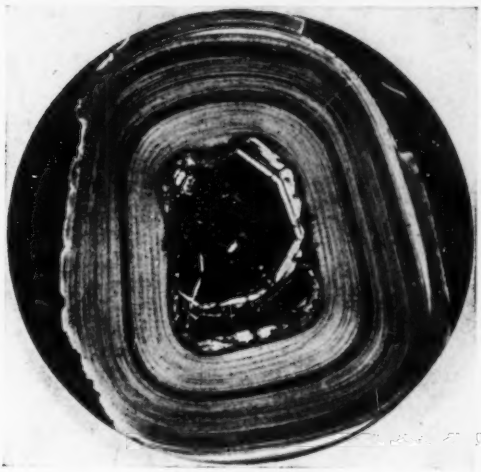
In the twenty-five specimens sectioned for petrographic study, no two have nuclei of exactly the same composition. The most common type of nucleus is a fragment of garnet-calcite-magnetite rock; other types are composed of various lime-silicate minerals or of ferruginous marble with minor amounts of pyrite and epidote. A yellowish garnet of the grossularite variety is the most abundant mineral. One specimen is a single-zoned garnet crystal enclosed by a comparatively thick covering of calcium carbonate (see Fig. 3, *A* and *B*).

Wrapped concentrically around the nuclei are rims of calcium carbonate ranging from a fraction of a millimeter to 5 mm. in thickness. Some of the sections and sliced pisolites were stained with Meigen's solution, known pieces of calcite and aragonite being used as controls. Many of the very thin layers proved to be aragonite, whereas the coarser and thicker layers were usually composed of calcite. The fine dark bands in the central portion of Figure 4, *A*, are stained aragonite. Figure 4, *A*, is the only photomicrograph showing a stained section; in the other photomicrographs (*B*, *C*, and *D*) the darker bands are due to impurities in the calcite.

The number of layers in a single pisolite ranges from a few to thirty or more (see Figs. 3 and 4). The thick coating on the specimen shown in Figure 4, *A*, contains approximately thirty bands, as counted under the microscope, although that number may be difficult to distinguish in the photomicrograph. The thin coatings on the specimens in Figure 3, *C* and *D*, show ten recognizable layers. It will be noted in Figure 3, *C* and *D*, that the thick basal layer of calcium carbonate is not entirely continuous over the garnet-epidote-calcite nucleus. The outer layer of the specimen shown in Figure 4, *C*, is much thicker than the earlier-formed layers and is made up of calcite crystals in semiradiating masses. A tendency toward a rounding of outlines



A



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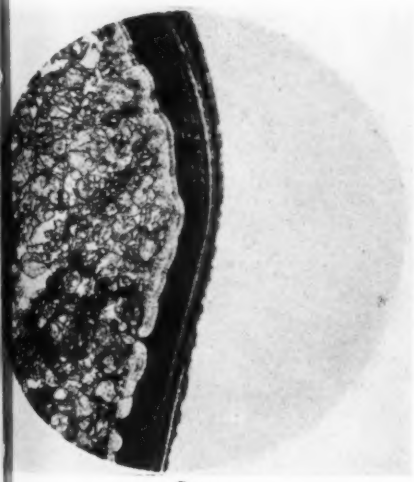
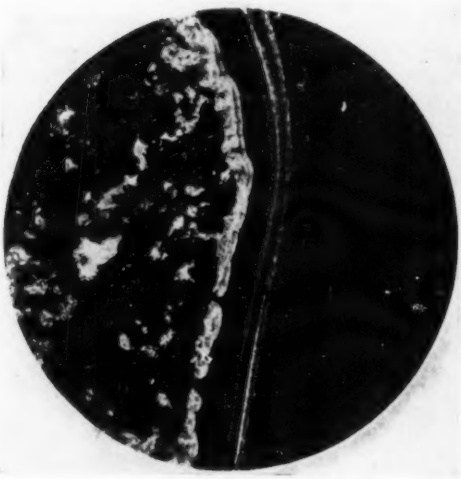


C



D

3.—*A*, "cave pearl" with zoned garnet nucleus, plane light (greatest diameter, 4 mm.). *B*, same as *A* but crossed *C*, bisque-surfaced pisolite; the nucleus is composed of garnet, calcite and epidote; the rim is 1 mm. thick. hat the first layer of calcite is not continuous over the nucleus. *D*, same as *C*, but under crossed Nicols.

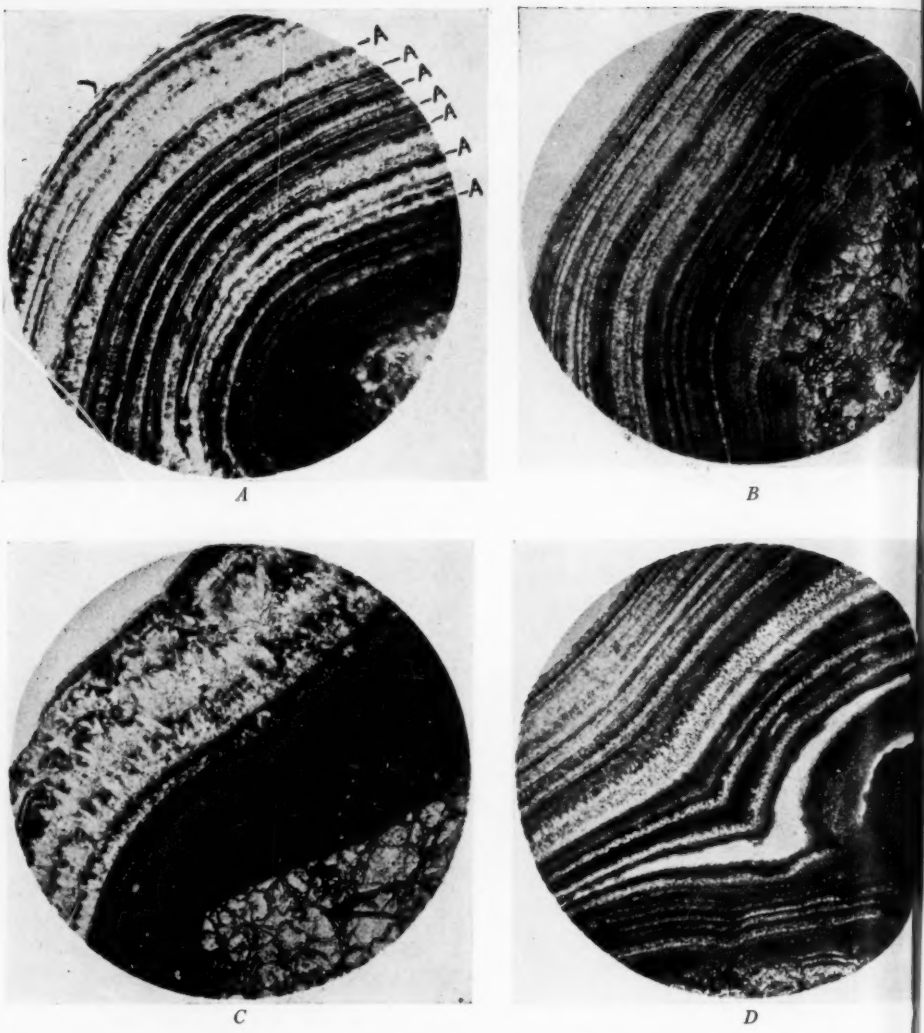


FIG. 4.—*A*, bisque pisolite; stained to show aragonite bands (marked *A*). Width of section seen in photomicro 1 mm. *B*, bisque pisolite; the darker bands are due to impurities in the calcite. Approximately thirty rings can be c on this specimen. Width of section in photomicrograph, 1 mm. *C*, bisque pisolite—a very fine early series of layers c by a very coarse outer layer of calcite. Width of section, 1 mm. *D*, smooth pisolite; the large node has been smoothe by variations in thickness of later layers. Width of section, 1 mm.

with growth of the calcium-carbonate coatings is shown in a number of the photomicrographs.

In Figure 4, *C*, an angular corner of the nucleus was evidently changed to a smooth curve by the first few growth layers. Figure 4, *D*, shows the manner in which a node and the associated reentrant angle formed during one stage of growth have been smoothed out by variation in thickness of the layers formed during later stages. The clear white band of calcite near the outer margin of the coating in Figure 3, *A* and *B*, is thick on the relatively flat sides of the specimen and thin or missing altogether on the corners.

HYPOTHESIS OF ORIGIN

After the tunneling operations were halted, the depressions were formed in loose rubble on the floor and along the walls of the adit by erosive action of localized drippings of water from the roof. It is evident that the development of some of the cups involved merely a smoothing of initial irregular depressions in the mine waste. Where the rubble consisted of fragments too large for erosion by impact and splash action, no depressions were formed (Fig. 1).

The floors and walls of the cups and adjoining surfaces of rubble and rock kept wet by mine waters were veneered by calcium carbonate; rims of some of the cups were raised by precipitation from overflow waters. Rock fragments and grains in the cups were similarly coated by calcium carbonate and, if agitation by dripping from the roof was sufficient to keep them in motion, became free-coated stones, or pisolites. The degree of smoothness or polish on the surfaces was dependent on whether the particles were merely rocked to and fro or whether they were turned over and over. This, in turn, depends upon whether the original particle was tabular or more or less equidimensional in shape, on the vigor of agitation, on the shapes of companion particles in the same cup, on the shape of the cup, and other circumstances. If accretional growth was not accompanied by motion of the particle for any considerable period, the fragments (or pisolites developed earlier) were cemented to the bottoms and floors of the cups.

This hypothesis provides an explanation for many of the features of the pisolites. The gradational sequence from a few cups with highly polished "cave pearls," through a greater number of cups with smoothed but only locally polished pisolites, to a still greater number of depressions with rough, free pisolites and many fixed pisolites is believed to be due to variation, from cup to cup, in the several controls mentioned above. The rate of dripping and, especially, variations in the rate are particularly important.

At the time of the examination (August, 1943), after at least six weeks without rain, both of the cups containing "cave pearls" were receiving drops from the roof at intervals of 5–15 seconds. To aid in determining whether the "pearls" were in motion, several were removed, marked with pencil dots, and carefully replaced in their original position; observation over a few minutes' time showed only a very slight movement of one of the marked specimens. To duplicate conditions of more rapid dripping, which certainly occur during the wetter seasons of the year, other waters from the roof were diverted so as to increase the rate to intervals of approximately 1 second; at that rate the water in the cups was in constant agitation, and several of the "pearls" were placed in motion

(or their motion was increased) so that they rotated about one-quarter turn in about 2 minutes.

It is believed that these slow rotational movements, which involve a rubbing-down or buffing of each film of calcium carbonate as it is deposited, are responsible for the high polish that characterizes the "pearls." The tendency for the "pearls" to assume a rounded shape is evidently due, in large part, to the relatively greater rubbing-down of the corners and edges than of the flattish or reentrant faces (see Figs. 3, *A* and *B*, and 4, *C* and *D*).

The distinct layering in the coatings is probably due to variation in agitation and nourishment (in both composition and supply), resulting from variation in the rate of dripping. While it is not likely that the control is strictly seasonal, it is interesting to note that the thirty-odd layers in some of the larger cave-pearl specimens compare closely with the known period of growth of the "cave pearls" (1901 or 1908 to 1943, 35–42 years).

In view of the fact that the cups were essentially brimful with "cave pearls" at the time of the examination, it appears that the "pearls" lodged on the slopes below the cups were dislodged from them as a result of slow accretional growth of all of the contained pellets.

One of the cups containing bisque-surfaced pisolites was receiving drips at approximately 10-second intervals; but in the majority of cups containing pisolites of this type the interval was much longer, and some received no drips during a brief period of observation. An intermittent rocking motion was noted in one cup holding bisque-surfaced pisolites. The fact that the corners and edges of some of the bisque pisolites are polished testifies to mutual rubbing, probably not accompanied by complete rotation. It is likely that with continued growth and rounding of outlines some of the bisque-surfaced forms may change into "cave pearls."

Some of the poorly defined depressions on the floor of the adit were receiving drips at varying rates, but many were supplied with water (during the dry season) only from seepage; most of the pisolites in depressions of this type are rough surfaced, and many are cemented in place. The inference is that continued nourishment by seepage waters during periods of no dripping and agitation tends to cause fixation.

There is evidence of marked changes in the rate and type of accretional growth in several of the cups. Figure 4, *C*, shows a change from early, finely banded growth layers (probably yielding a polished or bisque pisolite) to a thick outside layer of radial calcite yielding a rough exterior surface. Specimen 4, *D*, shows early uniform growth rings. Later, probably during a period of rest with lowered water level, the pisolite developed a node; and still later the growth habit changed again in such manner as to produce a smooth external form. As indicated earlier, the bisque-surfaced pisolite on the left in Figure 1, *A*, shows high polish on earlier growth rings. Changes of this type are believed to be due to variations in nourishment and agitation resulting from shifting in the positions of local orifices through which ground water enters the adit.

CONCLUSIONS

The brilliant polish that characterizes the Idaho "cave pearls" is believed to be the result of a buffing or rubbing-down of accretional layers of calcium carbonate as they are deposited, the buffing action being due to slow rotational movement

induced by agitation caused by dripping ground water. Since a rounded form is an essential prerequisite for such slow rotational movements, it is likely that the cave pearls described here did not have polished surfaces during very early stages of calcium-carbonate growth around nuclei consisting of angular fragments of mine waste. In other words, rounding of the pisolites by accretional growth and selective wear at edges and corners probably preceded, and made possible, the attainment of the high polish. This does not mean that all of the bisque- or rough-surfaced pisolites in the adit will eventually become polished, for the tendency to become smoothly rounded with growth is not systematic but depends upon a number of factors which vary from cup to cup—many once-free pisolites are now firmly cemented in place.

The pisolites described here were formed during a period not exceeding 42 years, the time interval since the adit was driven.

The theory of origin of the cave pearls described here corresponds in general with that proposed by Casteret for "oölites or cave pearls" occurring in natural caverns in France. Casteret states that "the fragments . . . . roll perpetually in the whirlpool [as they are being coated] . . . . and become almost perfectly spherical." Lee and Hess mention observing only a "slow rocking motion" in the cave-pearl nests in the Carlsbad Caverns. The rocking motion will suffice to prevent fixation, but it is not clear how it will produce the brilliant over-all polish that distinguishes "cave pearls" from the other calcium-carbonate precipitates formed by inorganic processes.

A GEOMAGNETIC SURVEY OF SOME BLADEN COUNTY, NORTH CAROLINA, "CAROLINA BAYS"

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Rutgers University, New Brunswick, New Jersey

During a recent field season a magnetometer survey comprising more than five hundred stations was carried out over approximately 15 square miles of previously unsurveyed area of the coastal plain of North Carolina. The area lies in Bladen County, about 9 miles northwest of Elizabethtown. Included within it are two single and one double oval or elliptically shaped depressions commonly referred to as "Carolina Bays."

One of the several hypotheses for the formation of the "Carolina Bays" is that proposed by F. A. Melton and William Schriever,[1] who were of the opinion that the bays resulted from the impact of a great many meteorites. A test of this hypothesis is the determination of the presence or absence of appreciable amounts of magnetic materials buried immediately below or close to the bays. Such materials should produce magnetic disturbances or "highs" that would be measurable at the surface by magnetometric surveying.

[1] "The Carolina 'Bays'—Are They Meteorite Scars?" *Jour. Geol.*, Vol. XLI (1933), pp. 52–66.

The plotted results of this survey show that pronounced magnetic highs are present. As shown in Figure 1, they are distributed as follows: high *A* seems associated with a bay which lies immediately to the west of the area surveyed; high *B* is seemingly associated with the double White Oak Bay; while highs *C* and *D* appear associated with the unnamed bay and Sessom's Bay, respectively.

The observed highs are variable in size, "relief," and position. Each one occurs well outside of the bay proper. Highs *A* and *B* occur to the east and south of the extreme southern end of the bays. High *C* is almost due south of the center of the unnamed bay, while high *D* occurs slightly west of a point immediately south of the southern end of Sessom's Bay.

Although previous reports of similar surveys have relied upon such magnetic data as presented here as a conclusive proof of the meteoritic hypothesis of origin of the bays, the question is here left open and the reader is free to arrive at any conclusion as to their origin that may be warranted by the facts presented.

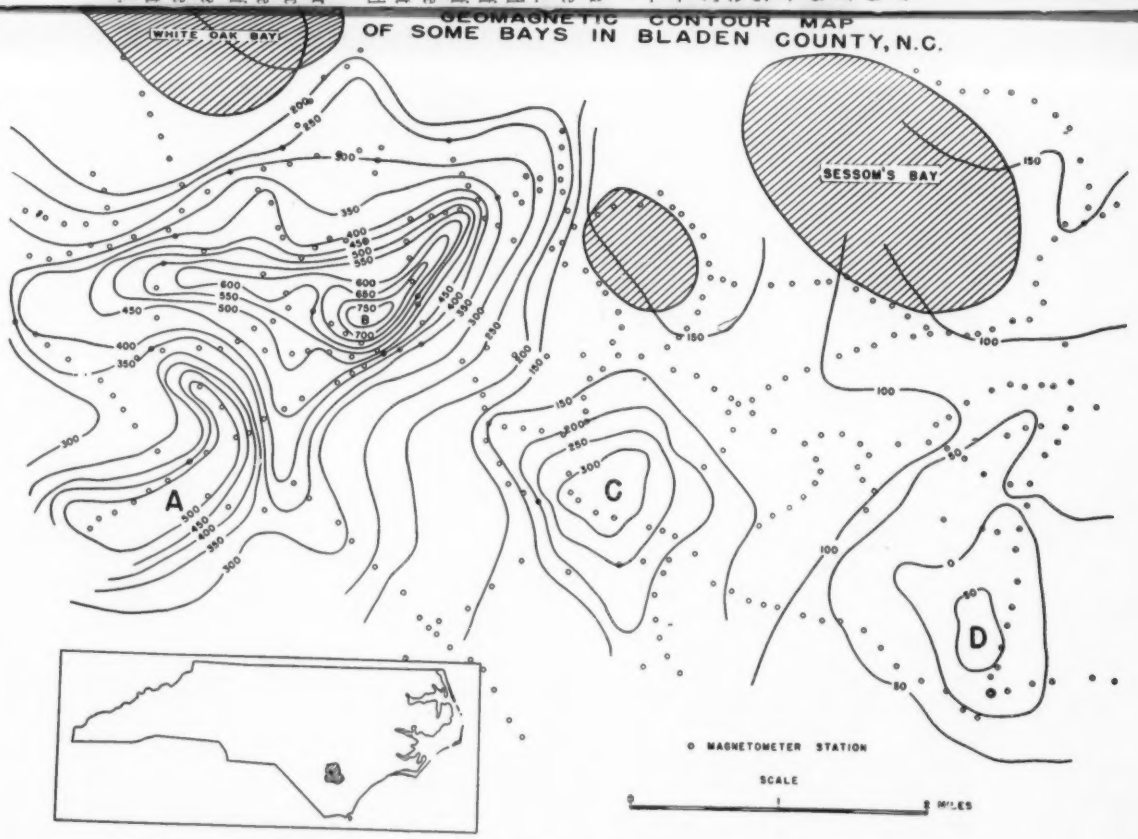

FIG. 1.—Geomagnetic map of a part of Bladen County, North Carolina. Contour interval = 50 gammas

REVIEWS

The Mineral Resources of Africa. By A. WILLIAMS POSTEL. Philadelphia: University of Pennsylvania Press, 1943. Pp. 105; figs. 19. $1.50.

This constitutes No. 2 in a series of African handbooks issued by the Committee on African Studies of the University of Pennsylvania. It is a summary and not an exhaustive treatise. The volume begins with a brief review, mainly statistical, of the world mineral situation, in order that Africa may be viewed in proper perspective. A comparison of African with world production (for 1938) shows that the largest items of Africa's mineral production are as follows:

	Percentage of World's Production
Diamonds	99.0
Vanadium	47.5
Gold	40.0
Phosphate	36.6
Chromium (ore)	31.6
Fluorspar	22.6
Manganese (ore)	21.6
Copper	18.0
Asbestos	16.0
Graphite (approx.)	15.0
Tin	10.8

All others are less than 10 per cent each. Africa has several mineral provinces that are productive. Along the northern rim of the continent, extending from Morocco through Algeria to Tunisia, is the great phosphate-rock belt. Associated with this belt are iron deposits of considerable importance. The largest copper province in the world extends from Katanga, Belgian Congo, southeast into Northern Rhodesia for a distance of 200 miles. This belt is also the largest world producer of radium and cobalt ores. The Bushveld igneous complex in Transvaal, an area of 37,000 square miles, and the Great Dike that runs through Transvaal into Southern Rhodesia, a distance of 330 miles, form another important province. The mineralization in this area includes platinum, chromite, and asbestos. The African diamond province has no equal in the world.

Most of the book is devoted to brief listing of the principal mineral occurrences of economic importance, classed under the usual captions of metals and nonmetallics. Geologic relations are not described, though they are illustrated in some of the figures.

In a brief chapter devoted to water power and supply the significant statement is made that "potential water power may be regarded as Africa's greatest resource." At present, however, not one-hundredth of this vast reservoir of energy is being utilized. In a continent almost devoid of mineral fuels the future of water-power development becomes of overwhelming industrial importance. The total water-power resources of Africa are estimated at three times those of Europe. More than half of this potential power is along the Congo River, mainly in Belgian and French territory.

An appendix deals statistically with the geographical distribution of Africa's mineral production and reserves. A short selected bibliography closes the volume.

This book is useful in portraying the broad features of the African mineral scene and furnishes a good starting-point for those wishing to pursue the subject more deeply.

E. S. BASTIN

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